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ABSORBENT MATERIAL FOR TYPE A RADIOACTIVE MATERIALS PACKAGING CONTAINING LIQUIDS

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ABSTRACT

The application of absorbent materials to the packaging and transport of liquid radioactive materials in Type A packages has not been reported in the literature. However, a significant body of research exists on absorbent materials for personal hygiene products such as diapers. Absorption capacity is dependent on both the absorbent material and the liquid being absorbed. Theoretical principles for capillary absorption in both the horizontal and the vertical plane indicate that small contact angle between the absorbent fibre and the liquid, and a small inter-fibre pore size are important. Some fluid parameters such as viscosity affect the rate of absorption but not the final absorption capacity. There appears to be little comparability between results obtained for the same absorbent and fluid using different test procedures.

Test samples of materials from several classes of potential absorbents have been evaluated in this study, and shown to have a wide range of absorbent capacities. Foams, natural fibres, artificial fibres and granular materials are all potentially useful absorbents, with capacities ranging from as little as 0.86 to as much as 40.6 grams of distilled water per gram of absorbent.

Two experimental procedures for evaluating the absorbent capacity of these materials have been detailed in this report, and found suitable for evaluating granular, fibrous or foam materials.

Compression of the absorbent material reduces its capacity, but parameters such as relative humidity, pH, temperature, and viscosity appear to have little significant influence on capacity. When the materials were loaded to 50% of their one-minute absorbency, subsequent loss of the absorbed liquid was generally minimal. All of the absorbent materials rapidly lost their absorbed water through evaporation within twenty-four hours in still air at 21 degrees Celsius and 50% relative humidity.

RÉSUMÉ

La documentation actuelle ne fait pas mention de l'application de matières absorbantes à l'emballage et au transport des matières radioactives liquides dans les colis de type A. Toutefois, il existe un important corpus de recherches sur les matières absorbantes pour les produits d'hygiène personnelle comme les couches. La capacité d'absorption dépend à la fois de la matière absorbante et du liquide à absorber. D'après les principes théoriques de l'absorption capillaire autant sur le plan horizontal que vertical, il est important que l'angle de contact entre la fibre absorbante et le liquide soit le plus aigu possible et que les interstices entre les fibres soient le plus petits possible. Certains paramètres des fluides, comme la viscosité, ont une influence sur le taux d'absorption, mais non sur la capacité d'absorption totale. Il semble y avoir peu de comparaison possible entre les résultats obtenus quand on soumet la même matière absorbante et le même fluide à des épreuves différentes.

Les échantillons d'épreuves de matières de diverses classes de matières absorbantes possibles ont été évalués dans la présente étude et montrent une grande variété de capacité d'absorption. Les mousses, les fibres naturelles, les fibres artificielles et les matières granuleuses représentent toutes des matières absorbantes utiles possibles dont la capacité d'absorption va de 0,86 à 40,6 grammes d'eau distillée par gramme de matière absorbante.

Deux procédures expérimentales pour évaluer la capacité d'absorption de ces matières ont été détaillées dans le présent rapport et se sont avérées utiles pour évaluer les matières granuleuses, les fibres et les mousses.

La compression de la matière absorbante réduit son absorptivité, mais les paramètres comme l'humidité relative, le pH, la température et la viscosité semblent peu l'influencer. Lorsque les matières ont été chargées à la moitié de leur absorptivité en une minute, la perte subséquente du liquide absorbé s'est avérée minime en général. Toutes les matières absorbantes ont rapidement perdu leur eau absorbée par évaporation en moins de 24 heures à l'air calme, à 21 °C et à 50 pour 100 d'humidité relative.

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ABSORBENT MATERIAL FOR TYPE A RADIOACTIVE MATERIALS PACKAGING CONTAINING LIQUIDS

A. INTRODUCTION

1. Background

The achievement of safety in the transportation of radioactive materials within Canada depends primarily upon the proper design of packaging for such materials as well as on the efficient manner in which the packages are handled, stored, transported and delivered. Many of the packages that are transported by commercial carriers contain relatively small volumes of radioactive materials which are used for medical research, diagnosis, treatment, sterilization and other industrial applications. In some cases, these radioactive materials are transported as liquids of various volumes which, under adverse conditions, could leak or break during storage, handling or shipment.

The packaging of radioactive material for transport in Canada is regulated by the Atomic Energy Control Board through the "Atomic Energy Control Act - Transport Packaging of Radioactive Materials Regulations" (SOR/83-740, 29 Sept. 1983). This regulation is based upon model requirements stipulated in the International Atomic Energy Agency (IAEA) Safety Standard "Safety Series No 6 - Regulations for the Safe Transport of Radioactive Materials" (published by the IAEA, Vienna, Austria). While several types or classes of packaging are specified, Type A packaging is one in which absorption is an important design criteria where liquids are to be transported.

Type A packages are normally light in weight, and contain relatively small quantities of radioactive materials, therefore requiring less radiation shielding and smaller packaging volumes. Packages in compliance with this Regulation must be able to withstand drop, penetration, compression, and vibration tests, as well as exposure to the equivalent of extreme climate conditions that may be encountered in normal transportation in Canada.

Where Type A packages contain radioactive materials in liquid form, they must also be provided with provisions for containment of the liquid in the event of spillage or breakage. The 1988 supplement to the IAEA Safety Series 6 with respect to Type A liquid packages specifies the following:

> "539. A Type A package designed to contain liquids shall, in addition:
>
> (a) Be adequate to meet the conditions specified in para. 537 above if the package is subjected to the tests specified in para. 625; and
>
> (b) Either
>
> (i) be provided with sufficient absorbent material to absorb twice the volume of the liquid contents. Such absorbent material must be suitably positioned so as to contact the liquid in the event of leakage;
>
> or
>
> (ii) be provided with a containment system composed of primary inner and secondary outer containment components designed to ensure retention of the liquid contents, within the secondary outer containment components, even if the primary inner components leak.
>
> However, the requirements given in subpara. 539(b) shall not apply in the case of a Type B package designed and approved for liquids which contains the same liquids having an activity equal to or less than the A2 limit for the authorized contents."

These regulations, in keeping with the IAEA philosophy, set a performance criterion but do not specify methods or materials which would guarantee compliance with it. The Atomic Energy Control Board therefore sought to evaluate the existing state of knowledge concerning liquid absorption into solid materials and to develop and apply certain basic laboratory test procedures to representative absorbent materials.

2. Objectives Of This Study

The purpose of this report is two-fold. The first objective is to conduct a literature survey and review the existing literature in order to identify and evaluate the parameters which govern the effectiveness of different types of absorbent materials used in Type A containers for the transport of liquid radioactive isotopes. The intention is to identify both the theory and mechanisms of liquid absorption as well as to identify existing data on absorption capacity of various materials, and existing test methods used to evaluate these parameters.

The second objective of the study is to develop standard test procedures and criteria for the selection of absorbent materials with the optimum combination of parameters suitable for such packaging, and to report on data collected from such test procedures conducted on samples of representative packaging materials.

Limitations inherent in this type of experimental study clearly exist. Laboratory tests cannot cover the complete range and complexity of fluids used in actual radioisotope transportation within Canada, nor can they simulate all possible combinations of adverse events which might occur in practice. In addition, changes to the experimental fluid which are made to control one property of interest will also result in changes to other properties, both physical and chemical, which are not under direct control. For example, the addition of ethylene glycol to water in order to reduce the freezing point of the mixture for low temperature testing will also change the viscosity, density, surface tension, etc of the test fluid. Therefore, the majority of the experimental tests will be conducted using distilled water, with only the minimum of modifying agents or non-aqueous fluids used. This strategy has been adopted on the basis that most of the liquid radioisotope solutions in commercial transport will be aqueous solutions or suspensions.

B. LITERATURE SURVEY

1. Outline Of Survey Methodology

An extensive literature search was conducted to identify and assess the parameters which govern the nature of absorbency and retention of liquids within different types of absorbent materials.

The resource centres utilized during this study included:

- Metro Toronto Reference Library
- McMaster University Science and Engineering Library (Thode)
- University of Toronto Science and Engineering Library
- University of Toronto Forestry Library
- Atomic Energy Control Board Library

The initial approach taken towards conducting the literature survey was to identify and research reference materials, journals, government publications and other related published documents. The search strategy focused on two basic objectives; first to identify and retrieve information with respect to the packaging and transport of radioactive materials and secondly to identify information on the physical properties and behaviour of absorbent materials such as paper, natural fibres and man-made fibres etc. Various on-line data base searches were conducted in order to obtain seemingly relevent documents relating to absorbent materials.

The initial search with respect to packaging and transportation of radioactive materials generated a plethora of citations which turned out to be almost totally related to type B packaging of such materials as spent nuclear reactor fuel and high level solid radioactive wastes. They dealt principally with radioactive waste transportation and ultimate disposal, transport of radionuclides in geological formations and through groundwater, development and testing of casks for high-level radioactive materials transport, spent fuel packaging techniques with respect to long term storage and final disposal, etc. The only direct reference to the use of sorbent materials with respect to radioactive materials is Robertson's (6) reference to the use of paper tissue or vermiculite to absorb spilled radioactive materials.

The approach was therefore shifted away from linking the words radioactive or nuclear with the other key words of the search strategy, and began to focus simply on absorbency without any reference to radioactive materials. This proved to be a much more fertile search strategy which ultimately netted several worthwhile papers.

The database and indices searched included:

1. Chemical Abstracts Index
2. Paper Printing and Packaging Abstracts
3. Packaging Science and Technology Abstracts
4. Paperchem
5. Citation Index
6. Nuclear Science Abstracts
7. Compendex Plus

The key words used for each active search included:

1. Absorb
2. Adsorb
3. Retention
4. Rentention of Liquid
5. Liquid Retention
6. Retention of Fluid
7. Fluid Retention
8. Soak Up
9. Clean Up
10. Package
11. Paper
12. Cardboard
13. Towel
14. Tissue
15. J Cloth
16. Fibre
17. Diaper
18. Tampon
19. Cotton
20. Polymer
21. Foam
22. Polyurethane
23. Polypropylene
24. Polyethylene
25. Sponge

In addition, professionals, associations, institutions and suppliers in the field of evaluating or manufacturing absorbent materials were identified, contacted, interviewed and/or researched. These included:

1. TAPPI - the Technical Association of Pulp and Paper Industries
2. CPPA - Canadian Pulp and Paper Association
3. SPI - Society of the Plastics Industry
4. Abitibi Research Centre, Sheridan Park
5. Kimberly Clark Education Department
6. European Patent Applications
7. Proctor and Gamble, Research Department
8. Stearns and Foster Ltd, Trenton
9. Precision Laboratories Inc., North brook, Ill.
10. Woodbridge Foam Ltd, Woodbridge, Ontario.
11. Scotfoam Corporation, Eddystone, Pa.
12. Can-Ross Environmental, Oakville, Ont.
13. Diversified Research Laboratories Limited, Toronto

Each of these individual organizations had some knowledge of absorbency or absorbent materials in relation to their particular field. The most potentially useful sources appeared to be those industries related to the baby diaper business. However, when approached, they were reluctant to discuss their knowledge in this very competitive, consumer-oriented market. A field visit to one independent testing laboratory confirmed that they do conduct testing for absorbency of commercial products but produced little or no information on the actual test procedure employed, as they were unwilling to discuss their specific procedures.

Transcripts of the proceedings were obtained for a number of Absorbent Products Conferences which are sponsored annually by Marketing/Technology Services, Inc., Kalamazoo, MI. The papers from these conferences proved to be a most fruitful source of information even though the subject matter was entirely directed to diapers and other personal hygiene products.

The proceedings of the triennial Symposia on Packaging and Transportation of Radioactive Materials were also reviewed for references to absorbent materials use in type A packaging. Very few references were found and the ones which were merely referred in passing to the need for absorbent materials in Type A packages without any further discussion or amplification.

Finally, technology development reports published by Environment Canada, entitled: "Selection Criteria and Laboratory Evaluation of Oil Spill Sorbents", 1976,(2) 1978,(3) 1983,(4) and 1985,(5) were reviewed.

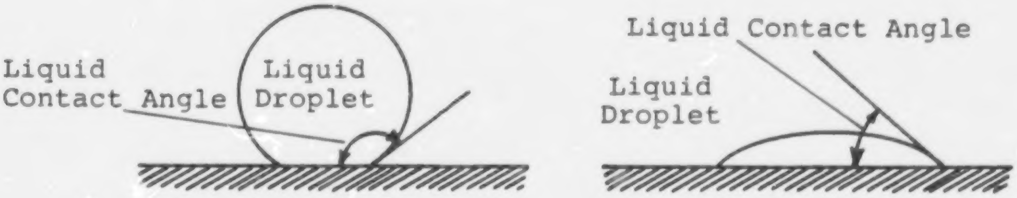
2. Literature Review - Theory And Principles

The phenomenon of liquid update or sorption by a solid is, in general, a combination of two physical processes; adsorption and absorption. Although the distinction between absorption and adsorption is not always clear-cut and the non-committal word sorption is sometimes used, the process of adsorption is considered to be essentially a surface phenomenon wherein molecules of the fluid are attached or adhere to the solid surface. In general, the more surface area the solid sorbent offers, the more adsorption capacity the solid will have for the fluid. The process of gas-solid adsorption has been extensively studied and at least three well-developed models exist for gas-phase adsorption onto a solid surface. They are the Langmuir Isotherm, the Freundlich Isotherm and the Brunauer-Emmett-Teller (BET) theory (8). However, adsorption is generally considered to produce only a monomolecular layer of fluid on the solid surface and hence, adsorption is not the principal mechanism of liquid uptake in most solid-liquid sorption processes of interest in this study.

Absorption refers to the liquid penetration into the sorbent structure of the solid by capillary action. Liquids retained by capillary action are thought of as having been imbibed or absorbed. In general, the phenomenon of imbibed and capillary-held water deals with mechanisms by which molecules of liquid are attached to the fibre surface or absorbed into the fibres or held by surface tension in capillary spaces in the fibre array (9). Such interstitial liquid is usually the largest fraction of the total fluid uptake by an effective sorption medium.

As a first approximation the capacity of an absorbing material to absorb and hold liquid is related to the void volume of the porous absorbing material. The potentially absorbing volume may be in tube-like structures as capillaries, irregular pores as they exit in natural cellulose fibre and open cell polymeric foams or it may be in the irregular spaces between or within granules of an amorphous material such as Fullers Earth.

In all cases the liquid must "wet" the solid absorbing material. This property is generally defined in terms of the contact angle that a small drop of the liquid will make with the solid surface. If the angle is less than 90 degrees it is wetting. If greater than 90 degrees it is a non-wetting combination as illustrated in figure 1 below. (11)



Non-Wetting Liquid   Wetting Liquid

FIGURE 1

(Diagram redrawn based upon Figure 14: Definition of Contact Angle from Wilson's Paper (12)).

Ideally, given the physical conditions which result in absorption of liquid the entire void volume will be occupied by fluid. To what extent this will actually take place will depend on surface tension and viscosity of the liquid, pore size and other physical characteristics of the absorbing medium.

Painter (10) used the following equation to define the void volume, Vv, in cm3/g, of a low density web of cellulose pulp fibres based on the concept that the total volume of web, Vw is equal to the fibre volume, Vf, plus the void volume Vv:

$$V_v = (V_w - V_f) = \frac{1}{D_w} - \frac{1}{D_f} \qquad (1)$$

Dw is the apparent density of the web material in the uncompressed state, in gm/cm3, while Df is the density of the individual cellulose fibres in the same units. This equation will always apply for void volume but it may be difficult to evaluate for many substances because Df is extremely difficult to measure.

Fluid capacity will approximate void volume where pore size is of the order of 100 microns or less. Where pore size is larger there will be a tendency for liquid to leak out where the physical conditions under which absorption took place are changed.

3. Basic Capillary Theory

The most thorough evaluation of the principles of absorbency was published by G.M. Aberson in 1970 (7). He identified that the rate of entry of a liquid into an absorbent pad of low density fibre mat depends upon capillary forces and the viscosity of the penetrating liquid. Consequently an understanding of the capillary phenomenon causing liquid absorption is necessary.

The important parameters that determine the rate of fully developed laminar liquid flow in a vertical cylindrical capillary are given by the Lucas equation: (R. Lucas, Kolloid-Z. Vol. 23:15 (1918).

$$\frac{dh}{dt} = \frac{r\gamma\cos\theta}{4\mu h} - \frac{r^2\rho g}{8\mu} \qquad (2)$$

where
t = time
μ = viscosity
h = liquid height in capillary
γ = surface tension
ρ = liquid density
g = acceleration due to gravity
r = capillary radius
θ = contact angle of liquid with absorbing surface

When the gravitational forces act in a downward direction the second term will remain negative, reducing the ultimate height of liquid in the capillary while for horizontal capillary movement the second term becomes zero so that the Lucas equation reduces to what is generally known as the Lucas-Washburn equation (E.W. Washburn, Phys. Rev. Vol 17:273 (1921)

$$\frac{dh}{dt} = \frac{r\gamma\cos\theta}{4\mu h} \qquad (3)$$

$$h = \sqrt{\frac{r\gamma\cos\theta}{2\mu}.t} \qquad (4)$$

The Lucas equation has been used by a number of researchers recently to correlate and explain wicking in pulp sheet.

This equation was derived for individual cylindrical capillaries and shows the influence of surface tension, viscosity, pore size, contact angle, and fluid density on wicking.

Wicking is an inherent property of absorbers and may be described in terms of both the rate at which an absorber takes on liquid and the height to which this liquid will rise when a block of absorber is dipped into the liquid. The height to which liquid will ultimately rise in a vertical capillary is given by solving the Lucas equation when the rate of wicking, dh/dt is zero.

$$h = \frac{2\gamma\cos\theta}{r\rho g} \qquad (5)$$

For horizontal capillaries, the Lucas-Washburn equation demonstrates that the wicking process never reaches steady-state (i.e. $dh/dt \neq 0$). For this situation wicking, or horizontal spreading of the fluid, continues at a slower and slower rate as h, the distance from the centre to the edge of the wetted mass, increases without limit. The rate for horizontal wicking is always faster for large pores than for small pores.

Equation (5) demonstrates that the factors governing the ultimate height of fluid wicked into a capillary and hence, the capacity of a sorbent made up of numerous capillary void volumes is controlled by properties of both the fluid (density and surface tension) and the sorbent (pore size) as well as the contact angle which is a function of both the fluid and the sorbent material in combination. The viscosity of the fluid does not influence the final height wicked although it does influence the rate at which wicking takes place. The final height reached is also directly related to the surface tension. The lower the surface tension the lower the final height reached.

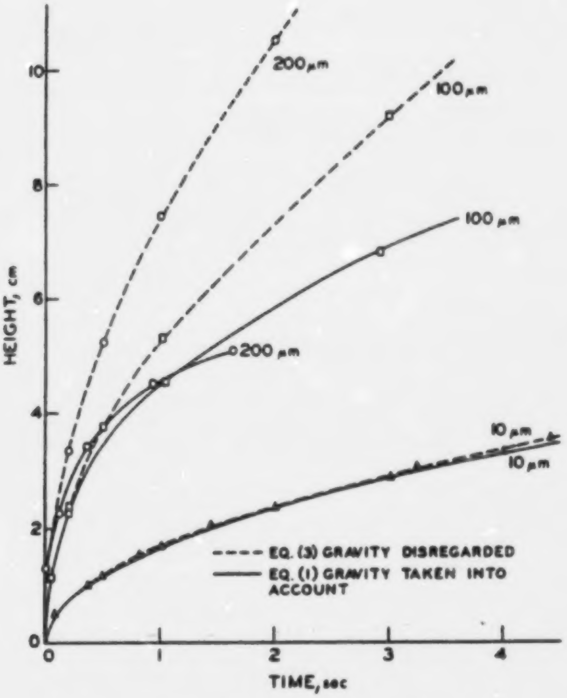


Fig. 22.1. Effect of gravity on rate of capillary rise in narrow and wide capillaries (θ = 40°).

FIGURE 2

In Figure 2 above (Figure 22.1 from Aberson's original paper), curves have been constructed that represent the calculated rise of water in cylindrical capillaries for selected values of r and θ, using the Lucas and Lucas-Washburn equations (referred to as equations (1) and (3) respectively in the above diagram). The curves reveal that the importance of the influence of gravity depends on the width of the capillary for a given contact angle θ. When the capillary radius is less than about 10 μm, the difference between the two equations is negligible. It can therefore be concluded that gravity has a negligible effect in opposing capillary rise in capillaries with r < 10 μm so that the Lucas-Washburn equation is a suitable approximation. However, as the capillary radius increases above 10 μm, the gravitation effect becomes increasingly significant. That equation 3 is obeyed in systems consisting of irregular capillaries with varying shapes and sizes was demonstrated by measuring the rate of liquid rise in vertically suspended strips of paper, multifilament yarns, and cotton fabrics. Straight lines were obtained by plotting the height of rise versus the square root of time as predicted by equation 4.

However for both equation 2 and 3 dh/dt becomes infinitely large when h is infinitely small. This means that at the onset of capillary rise a stationary meniscus suddenly must acquire an infinitely large rate of ascent. Deviations can be expected at this stage and since at the initial stages of absorption dh/dr approaches the value of r deviation can be expected to be greatest with pores of larger radius. Figure 3 (Figure 22.2 from Aberson's original paper) indicates the difference between calculated and observed rate of rise in a glass capillary for a radius of 242 µm.

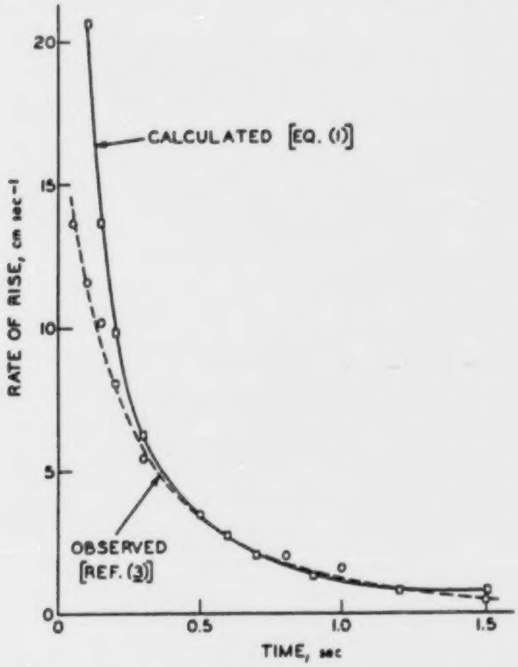


Fig. 22.2. Difference between calculated (Eq. 1) and observed (Ref. 3) rate of rise in a glass capillary ($r = 242\ \mu m$).

FIGURE 3

Aberson summarized this theoretical model by stating that the rate of capillary penetration of a given liquid depends upon the capillary radius r and on the angle of contact θ of the liquid with the capillary wall. Consequently, a study of the factors affecting the absorbency of loose fibre beds must involve a study of contact angles between the absorbing liquid and fibres, and of pore sizes existing in the dry and wet fibre pads.

The paper then goes on to demonstrate that it is possible to determine experimentally the effective radius of the pores as well as the contact angle through measurements of the rate of rise of a given liquid since the curve of the capillary rise against the square root of time will yield a slope as follows:

$$\text{slope} = \sqrt{\frac{\gamma r \cos\theta}{2\mu}} \qquad (6)$$

If θ is zero, cos θ is 1 and r can be calculated because the surface tension and viscosity are both known. By using dilute solutions of surfactants the contact angle can be made to approach zero (reported as 9 ± 3 degrees for a 0.1% solution of Teepol).

Once the effective pore radius is calculated for the absorbent using the surfactant solution data, this value can be inserted into the equation for the slope of the pure water data to obtain a contact angle for water with this absorbent, as follows:

$$\theta = \cos^{-1}\left\{\frac{2\mu'(\text{slope})^2}{\gamma r}\right\} \qquad (7)$$

Aberson's experiment demonstrated that the addition of a surface active agent to water slowed down the rate of absorption and reduced the absorption capacity of wood pulp samples. This is due to the fact that the surfactant lowers both the surface tension and the contact angle of the liquid. Since viscosity and effective radius are identical, according to equation 4 the rate of rise is proportional to cos θ. Since cos θ is taken as 1 for the surfactant solution, the rate of rise in pure water will exceed that of the surfactant solution only when

$$\gamma_\omega \cos\theta_\omega > \gamma_\tau \cos\theta_\tau$$

then

$$\cos\theta_\omega > \gamma_\tau/\gamma_\omega$$

γ_ω = surface tension of water = 72.4 dynes/cm
θ_ω = contact angle with water
γ_τ = surface tension of aqueous Teepol solution = 32.8 dynes/cm
θ_τ = contact angle with Teepol solution = 0

$$\cos\theta_\omega > \frac{32.8}{72.4}$$

$$\theta_\omega < 63°$$

Consequently addition of Teepol will slow down the rate of rise when $\theta w < 63$ (ie: easily wetted solids) but will improve it when $\theta w > 63$ (ie: poorly wetted solids). Similar effects will be seen with other concentrations or with other surface active agents, but the exact cross-over point will vary.

Aberson's work developed several general principles of absorbency in cellulose pulp which can be summarized as follows:

- The pulps with the fastest rate of absorption contain fibres with the smallest contact angle;
- All other factors remaining equal, the highest rates of absorption were associated with the lowest liquid-holding capacity.
- For capillary absorption in the vertically upward direction there is an optimum bulk density of the pulp for maximum rate of absorption. This is due to the increased gravitational effect on capillary absorption in wider pores countering the increased void volume of less dense pulp to result at some point in a net negative effect on rate of absorption. Such a maximum would not be expected to occur with horizontal or downward capillary absorption where the liquid flow is not opposed by gravity.
- For pads of equal density, the thicker fibres will show a more rapid initial uptake but a lower total capacity than thinner fibres. Figure 2 illustrates the crossover point for a 100 µm and a 200 µm capillary at approximately 1.2 seconds. The cross-over point for the 100 µm and 10 µm capillaries would occur at times well beyond the time scale of this chart.
- Except when very small, fibre length has a negligible effect on rate of absorption; but the liquid holding capacity improved with increasing fibre length.
- The capacity of a pad to withstand collapse while absorbing and carrying a fluid load is reflected in higher absorption rates.

Dr. Dale Wilson extended Aberson's work by presenting a solution to the Lucas equation which he claims to be valid for vertical wicking for all pore sizes. The Wilson equation is given below.

$$t = \frac{H_{ss}}{B} . \ln Z - \frac{H_{ss}}{B} . \left(1 - \frac{1}{Z}\right) \qquad (8)$$

Where B = dimensionless gravity factor

= $r^2 \rho g / 8\mu$

Hss = steady state vertical wicking height

Z = dimensionless reciprocal height

= $H_{ss} / (H_{ss} - h)$

This equation is also more reliable for the real world case of a distinct pore size distribution within the pulp fluff rather than Aberson's idealized case of perfect capillaries with uniform pore size. The Wilson equation suggests that initially the wicking rate is greatest in the large pores. This is seen in equation 2 (the Lucas equation) where the rate is directly proportional to pore radius. At longer times, and at the greater heights, the wicking rate is faster in small pores than in large ones. This cross-over of wicking rate is not seen in previously used approximate solutions but is only seen in the solution to the Wilson equation.

4. Cellulosic Absorbents

Cellulosic absorbents are used in vast quantities in such commercial applications as baby diapers, sanitary napkins, facial tissue, paper towels, etc. These products consist of a mass of cellulose staple fibres, either bulked into a low density fluff for diapers and napkins, or formed into a web for tissue and towelling. These cellulose fibres may be processed in special ways, both mechanically and chemically, in an effort to enhance their water absorption capacity. Each manufacturer has developed unique processing methods to generate a product within the specific set of characteristics which are considered to be most important for the particular application. Hence there are, in effect, as many different types of "cellulose" as there are applications for the material.

The most important source of information on the absorbency of cellulose is the literature pertaining to the diaper industry. A technical conference, known as the Absorbent Products Conference, is held yearly in North America to discuss developments in this multi-billion dollar industry. However, because of the highly competitive nature of this business, most published literature on the subject deals in generalities rather than specific details. In addition, the papers which are available, deal almost exclusively with the performance of absorbent materials with respect to urine.

The sorption capacity of cellulose pulp is not generally quoted in the literature. However, Wilson (12) has indicated that the capacity of two cellulose pulps from separate sources ranged from 7.6 to 11.4 ml/g for source A and from 9.0 to 11.7 ml/g for source B, depending upon the density of the pulp fluff (range 0.10 to 0.06 g/cc). These values were obtained for southern softwood kraft pulp tested with a 1% saline solution. Aberson (7) gives the water holding capacity of a sample of bleached kraft southern pine pulp as between 11.0 and 12.5 ml/g of fibres for a pad of density 0.063 g/cc. Hillgren and Zoller (13) describe the liquid retaining capacity of the cellulose pulp which they tested as 14 g/g without addition of super absorbent polymer.

Aberson (7) also gives the absorption capacity of pads prepared from rayon (reconstituted cellulose) of different fibre thickness but of equal density (0.08 g/cc). The thick fibre pad will have fewer fibres than the thin fibre pad and therefore fewer and larger pores. The thicker fibres might also be expected to confer rigidity to the pad. His experimental results indicated an absorption capacity of 9.5 ml/g of fibres for 20 denier fibres and 12.4 ml/g of fibres for the 3 denier fibres, even though the void volume of both pads would be equal (i.e. Dw and Df are the same). Obviously in this case the void volume is not completely filled with liquid, at lest for the larger diameter fibres. Aberson did not explore this issue further in his paper.

Ehredt (1) suggests that the absorbency by weight of a cellulosic absorbent (exact nature unspecified) is 221% of its own weight (2.21 x weight). Although this paper does not specify the fluid used in this determination, the article focuses on the use of absorbents in manufacturing facilities to clean up spills of oily materials and the absorption capacity is apparently based on the oil absorption capacity.

Finally, Can - Ross Environmental Services Ltd (14) list the absorbency of their SorbX pad as 15 times its own weight in water (15 X weight). This pad is constructed of a cellulose fluff core with a non - woven polypropylene backing sheet.

No specific references were found regarding the effects of such parameters as compression, temperature, pH, viscosity, humidity, etc on the absorbent capacity of these materials. However, it is of interest to note that the absorption capacity quoted by Wilson of 11 to 11.7 ml/g for two samples of southern softwood kraft pulps of density 0.06 g/cc evaluated with 1% saline solution is comparable to the absorption capacity of 11.0 to 12.5 ml/g as given by Aberson for pads of bleached sulphate Southern pine pulp of 0.063 g/cc density tested with water. This would infer that the addition of 1% salt does not seriously alter absorption capacity of cellulose fluff materials.

5. Mineral Absorbents

Although the application and use of mineral sorbent materials is widespread there appears to be more art than science applied to the selection and use of these materials. No widespread and general theoretical basis for the process of liquid absorption into a solid was found in the literature. Many types of minerals are marketed as sorbents for various purposes.

It is evident that the most effective mineral sorbents consist of granules containing multiple crevices between the mineral plates as with vermiculite or fine skeletal structures with many open pores and capillaries as with diatomaceous earth. The sorption process is therefore one of liquid uptake by capillary action as with cellulosic materials. However, no direct references could be found in the literature to confirm this hypothesis.

In 1988, Ehredt (1) published an article entitled "Evaluating Absorbent Materials" which discussed the use of conventional clay absorbents and new polymeric absorbent socks in industrial applications such as controlling leakage and spills of hydraulic fluid.

Figure 2 of this paper suggests the following absorbency by weight for various sorbents (fluid unspecified).

Clay	15%
Cellulosic	221%
Vermiculite	400%
Polymeric	960%

This paper is unfortunately too broad and non-specific to be of much value in the present search. Discussions with individual suppliers has indicated that typical water sorption capacity for diatomaceous earth is 130% of its own weight (15) and for one montmorillonite clay it is 116-125% of its own weight (16). No other literature citations were found regarding clay absorbents.

The literature does not mention any effects of other variables on the sorption capacity of clay minerals.

6. Special Polymers

A good deal of general information is available with respect to the performance of diapers and other personal hygiene products from the diaper industry, both in North America and particularly, in Japan. This information centres around the development and use of what are generically called super absorbent polymers (SAP) which were first introduced into disposable diapers in 1983 in Japan (17) and have undergone explosive growth in North America in the last 3 years (21).

These are water-swelling specialty polymers whose function is to immobilize as much fluid as possible without releasing it when the structure is compressed (18). They are cross-linked hydro-gels which tie up the water molecules by incorporating them into their chemical and physical structure so that the cross-linked polymer is changed and a water insoluble gel material results. In this gel structure the water is fixed, even under pressure. This is an important difference in comparison with cellulose fluff pulp as absorbent material where the weakly bound fluid is released immediately if the pressure increases.

They are based upon either synthetic materials such as polyacrylic acids or upon natural materials such as starch and cellulose which have been modified to impart enhanced performance (19). SAP for diaper use is mainly the sodium salt of a cross-linked polyacrylate, though there are many kinds of super absorbents (17).

The table below lists only a few examples of some of these products (20).

Super Absorbent Type	Example (Producer)
Starch Derivatives (Starch Graft Polymers)	SGP Absorbent polymers (Henkel Corp) Sanwet IM1000 (Sanyo Co. Ltd) 35A-100 Embossed Tissue (Grain Processing Corp)
Cellulose Derivatives	Aqualon (Hercules) CLD-2 (Buckeye Cellulose)
Modified Rayons	Absorbit (American Enka) "Quel" (Chemiefaser Lenzing)
Synthetics (Mostly Acrylics)	Permasorb (National Starch) DWAL (Dow Chemical Co.) Surpon A-381 (BF Goodrich) Aqualic L-73 (Nippon Shokubai Co.)

Dean, Owens, Moore and Schoggen, in their patent (22), describe hydroforming gel materials including polyacrylamides, polyvinyl alcohols, ethylene maleic anhydride copolymers, polyvinyl ethers, hydroxypropyl cellulose, carboxymethyl cellulose, polyvinyl morpholinone, polymers and copolymers of vinyl sulfonic acid, polyacrylates, polyvinyl pyridine, isobutylene-maleic anhydride copolymers and modified natural materials such as hydrolysed acrylonitrile grafted starch and acrylic acid grafted starch and cellulose.

All of these super absorbent polymers have a very high ultimate capacity for water absorption (30-40 g/g material) (9). Liquid retention under pressure can be on the order of 70-80 per cent versus 10-20 per cent for an unstablized mass of staple fibres (9). However, they absorb fluid more slowly than fluff pulp webs since the particles must swell as fluid diffuses into them, whereas pulp fibres must only have wettable surfaces for the fluid to wick between them.

In the absorbent core of disposable products, cellulose fluff pulp is still the major component, (19) and developments are also taking place in this field as well to enhance the performance of the absorbent fluff. Techniques currently used include sodium hydroxide treated cellulosics, or acrylics (23) or combinations of cellulose pulp and special spurt-spun polyethylene fibres thermally bonded together (12) or twisted stiffened cellulose fibres (24). Hellgren and Zoller point out that in order to increase the liquid-containing capacity in absorbent articles efforts have been made to utilize so-called super absorbents. Because of their poor liquid transmitting properties, however, it has proved difficult to take advantage of the otherwise high liquid-retaining potential of these super-absorbents. Furthermore the cost of producing absorption materials with the aid of super absorbents are considerably higher than those connected with the use of so-called cellulose fluff-pulp, for example (13).

Hellgren and Zoller's patent describes a complex absorption matrix consisting of 70-95% of at least one type of absorbing fibres, preferably so-called cellulose pulp-fluff, 2-20% of a binder activated by heat and preferably in the form of bonding fibres, such as Pulpex E-388 manufactured by Hercules Company and 2-25% of a highly absorbant material such as the super absorbent Sanwet marketed by the Sanyo Company of Japan.

The bonding fibres will melt at their bonding temperature and thereby bind together the absorption fibres and the super absorbent material into a coherent matrix, which has greater liquid-transmitting capacity than that of the separate components. By varying the density of the material from its lowest value at the tissue contact surface to its greatest value at the opposite surface of the material liquid can be trapped and retained away from the low-density surface, gaining in this way the advantage that the surface facing the wearer will not be wetted but remains essentially dry with a pleasant feel to the wearer.

A mixture of 84% cellulose fluff/8% bonding fibre/8% SAP has liquid retaining capacity of 27 grams per gram of absorption material, while without SAP it had 14 grams/gram and SAP itself had 32 grams/gram.

Dean, Owens, Moore and Schoggen of the Buckeye Cellulose Company (22) have patented an absorbent structure containing individualized cross-linked cellulose fibres which have primarily intra-fibre chemical cross link bonds. That is the cross-link bonds are primarily between cellulose molecules of a single fibre rather than between cellulose molecules of separate fibres. The crosslinking agents used are C2-C8 dialdehydes such as glutaraldehyde and glyoxal, C2-C8 dialdehyde acid analogues having at least one aldehyde functionality such as glyoxylic acid and oligomers of such C2-C8 dialdehyde and dialdehyde acid analogues. These compounds are capable of reacting with at least two hydroxyl groups in a single cellulose chain or on proximally located cellulose chains within a single fibre.

Moore, Owens and Shoggen of the Buckeye Cellulose Corporation (24) have also patented a method of producing twisted stiffened cellulosic fibres and absorbent structures made therefrom. These individualized, curled, stiffened, highly twisted cellulosic fibres are stiffened by chemical treatment with a variety of monomeric crosslinking agents, including C2-C8 aldehydes, and dialdehydes. They can provide superior wicking ability and absorbent capacity in a thinner pad structure than conventional cellulose fluff pulps. Since the effectiveness of polymeric gel-forming materials (SAPs) may be limited by an absorbent structure's ability to transport fluid to the polymeric gelling material or to other portions of the absorbent structure due to swelling of the polymeric gelling material, the enhanced wicking ability and absorbent capacity is considered important.

Tuerk and Werner (25) have discussed the testing of super absorbent polymers and the influence of some specific parameters on these test results. They point out that the nature of the test fluid can influence the absorbent capacity determined. The fluid uptake of polyacrylate SAP as a function of the sodium chloride concentration or urea concentration of the fluid is illustrated in Figure 4.

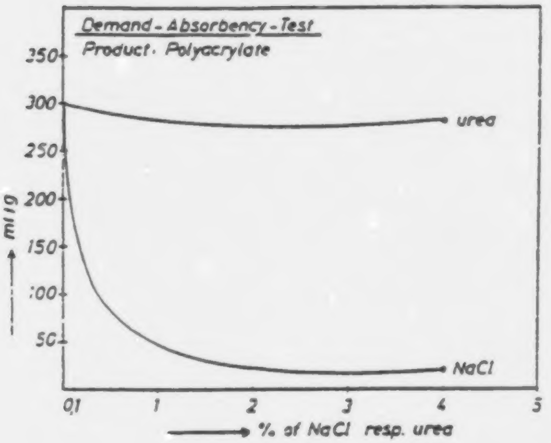


FIGURE 4

They also found that at pH values below 7, the fluid uptake capacity decreased gradually with increasing acidity and dropped by as much as approximately 40% at a pH of 3.5 irrespective of whether the fluid was water or urine. They also found a slightly higher absorption capacity (approximately 10% higher) when the SAP was tested with synthetic urine at 37.5 degrees C as opposed to 21 degrees C as illustrated below.

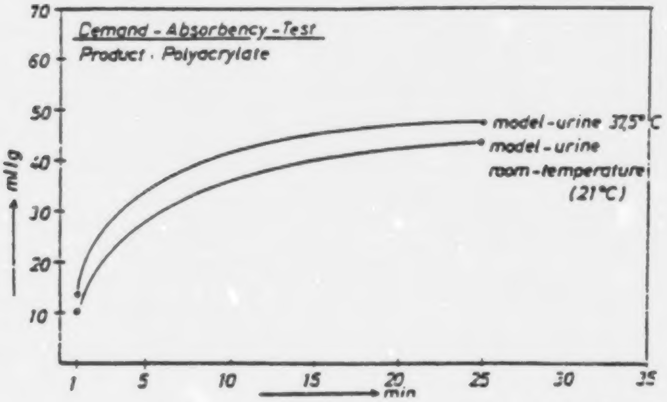


FIGURE 5

Most synthetic polymeric foam materials such as polystyrene, polyurethane and phenol-formaldehyde or urea-formaldehyde foams are hydrophobic and water is not readily absorbed within their structure (26). Indeed, the water resistance of these products are a valuable property in many applications such as disposable expanded polystyrene coffee cups and polyurethane foam insulation of refrigerator or freezer cabinets. In addition, most polymer foams are produced as a "closed-cell foam", where each cell or air bubble in the foam is separated from any other by a thin membrane of solid polymer. Thus the void volume of the cells are not interconnected.

By suitable adjustment of the physical and chemical parameters of the manufacturing process however, most foams can be produced as "open-cell" foams where the void volume of the individual cells are interconnected. These internal void volumes therefore permit even an essentially hydrophobic material such as polyurethane polymer to imbibe and retain water within its void volume.

Recently, Scotfoam has introduced a thermally reticulated polyether polyurethane foam specially formulated to incorporate a super absorbent polymer powder throughout the three-dimensional foam structure. According to the manufacturer's literature, it's absorbency for a one hour test is 36.8 grams of water per gram of material and 20.2 grams of 1% NaCl per gram of material (27). It's ability to retain water while suspended in air or vigorously shaken by hand is also reported to be very good (35.7 g/g and 33.2 g/g respectively). Interestingly, the addition of 1% NaCl to the water apparently markedly affects the performance on these two tests however (9.8 g/g retention after 30 seconds drainage and 7.2 g/g retention after shaking vigorously by hand six times).

No other references were found in the literature with respect to the absorbency of synthetic polymeric foam materials.

The Environmental Emergency Branch of the Environmental Protection Service, Environment Canada, has carried out a series of evaluations of oil spill sorbents over the past twelve years which have been directed specifically at commercially available oil spill sorbent materials. These studies have been periodically updated to keep abreast of new products released to the market. (2) (3) (4) (5).

They developed methods of evaluating the following parameters:

- sorption capacity (the amount of oil that a particular material is capable of picking up, given in grams of recovered oil per gram of solvent, when tested in an oil/water medium)
- the maximum sorption capacity (the maximum pick-up capacity of oil by a sorbent tested on oil) only and
- the oil/water ratio of the fluid recovered from the sorbent.

The most recent update, (EPS 3/SP/1 June 1985) summarizes the results on 5 organic and 13 synthetic polymer absorbents.

A compilation of the findings from these studies is given in the attached Appendix A, as these materials might be of value in shipments containing oil-based fluids as opposed to water-based fluids.

7. Testing Methods

Absorbency tests are used to evaluate a material's characteristics as an absorbent. There are three important properties of absorbents which are generally of interest:

- absorent capacity
- rate of absorbence
- amount retained under pressure

The ideal test for each of the properties would exactly duplicate the conditions under which the material would normally be used. Unfortunately in many cases duplication of these conditions is neither feasible nor practical. Most test methods therefore represent some compromise between a total replication of actual use conditions and a predetermined, reproducible set of standard conditions. Since absorbents have such a wide range of application from the operating rooms and wards of hospitals to laboratory benches, industrial facilities, emergency response teams and oil spill clean ups, as well as diapers and personal hygiene products, the conditions which absorbency testing attempt to model are just as varied and have resulted in many companies developing their own unique test methods. An examination of the technical patent literature reveals that a variety of tests are used to determine absorbency. Workers in this field generally do not have available to them industry-accepted tests such as ASTM procedures.

ASTM Test Method D1117- "Standard Methods of Testing NonWoven Fabrics" contains one section (Section 5) on determining Absorbency Time and Absorptive Capacity which is frequently used to evaluate sheet, pad, and bulk type absorbents. Section 5 of ASTM Method D-1117 has been reproduced, with permission, as Appendix B to this report. Illustrations of the test apparatus (Figures 6 and 7) are reproduced from the paper by Dr. Richard E. Seaman (9).

Several good reviews of absorbency testing methods have been published in the literature. These include reviews by Paul J George of BF Goodrich Chemical Group (20), Dr Richard E. Seaman (9) Dr Wolfgang Tuerk and George Werner of Stockhausen GMBH, (25) E.V. Painter of Johnson and Johnson, (18) (10).

The test methods reported in the literature can be divided into two basic groups (25)

-Liquid Excess Methods

-Demand Absorption Methods

The general principle of the liquid excess method is the contacting of the absorbent with an excess of test fluid, i.e. the applied amount of test fluid must exceed the maximum absorption capacity of the tested product. A representative preweighed sample of the absorbent under test is usually immersed completely in the fluid for a preset time, removed and allowed to drain for a known period of time, and then reweighed to establish total capacity. ASTM D-1117 is the best known of such tests. It determines both the absorbency time and absorptive capacity. A 76mm square preweighed sample is rolled into a cylinder and placed in a wire cage retainer, then dropped into a beaker from a height of 25mm. The time to completely wet the specimen is recorded as well as the weight gain after submersion for 10 seconds and draining on end for 10 seconds. However this test procedure was developed for non-woven fabric material and may not be directly transferable to other absorbent materials.

The common principle of the demand absorption tests is that one end of a calibrated liquid reservoir is connected to a sample holder, where the static liquid pressure is kept to zero. When the test sample comes into contact with the liquid it sucks just the amount of fluid out of the reservoir which it is capable of absorbing. Such tests enable liquid absorption to be followed as a function of time, while simultaneously indicating the maximum amount of liquid absorbed. The absorptive properties can be determined with or without loading or compression.

Seaman (9) describes a capillary absorption test in which the absorbing material is placed in a funnel having a fritted glass filter in the base. A burette full of liquid is positioned beside the funnel and connected to the base of the funnel with a piece of flexible tubing. The funnel is adjusted so that at the start of the test the liquid just touches the sintered glass. The burette stopcock is opened and the liquid moves up into the absorbent by capillary action. A pressure plate on top of the absorbent can be changed to affect bulk density and vary absorptive capacity. Absorption can be followed by noting the change in liquid level in the burette. The apparatus is illustrated in Figure 8.

Dr Paul George (20) describes a demand absorbency test similar to Seaman's capillary absorption test. The fritted glass funnel is replaced with a pair of metal plates between which the absorbent material is held with a compression loading as required. Three pieces of 9 cm. Whatman No.4 Qualitative filter paper are initially placed between the plates, compressed to 1kPa pressure and saturated with liquid from the burette for 20 minutes. Then a 0.1 to 0.2 gram sample of absorbent is placed on the prewetted filter paper, the top plate and appropriate weight replaced on top of the absorbent pad, the initial burette reading recorded and the stopcock opened to allow wicking of fluid out of the burette into the absorbent. George recommends readings at 1,2,3,5,10,15,20,30 and 60 min after opening the stopcock. The demand absorbency test apparatus is illustrated in Figure 9-1.

Painter (18) describes the use of a Gravimetric Absorbency Testing System (GATS) which is a commercially available apparatus from M/K Systems Inc., Danvers, Mass. He used the apparatus to evaluate a series of super absorbent polymers in order to determine absorbent capacity, rate of absorption and retention of liquid. The GATS consists of a fluid reservoir (12 on attached Figure 9-2) suspended on an electronic balance (16 on Figure 9-2) by means of a spring (39, Figure 9-2) which keeps the fluid level constant whenever fluid moves either into or out of the reservoir by the means of the dip tube (22 on figure 9-2). Adjustment of the sample level in relation to the fluid reservoir level is made by turning the hand wheel on the elevator screw assembly (36 on Figure 9-2) on which the sample holder plate (26 on Figure 9-2) is mounted. The electronic balance provides the mass of the fluid reservoir to 0.04g and the screw elevator adjusts height to 1mm. A series of two weights (30g and 684g respectively), each 5.08 cm in diameter are stacked vertically above the sample on the elevator platform. The two weights together produce a load of 3.45 kPa while the small weight alone produces a load of 0.14 kPa. The test cycle consists of 30 minutes absorption under 3.45 kPa loading, then 20 minutes absorption under a reduced loading of 0.14 kPa and finally 10 minutes of recompression to 3.45 kPa.

Vertical wicking tests are also a form of demand absorbency tests. The EDANA wick test (12) uses a 3.18 cm wide strip of the absorbent pad, suspended and supported by a rod. The lower end of the pad is submerged in the test fluid reservoir and the height to which the fluid wicks is recorded at suitable time intervals. In order to facilitate visual evaluation of liquid distribution in samples, dyes such as Rubine S (biological stain) G.I. 42685 have been added to the test liquid (11).

Horizontal wicking has also been evaluated in a variety of apparatus. The drop absorbency test uses a 10 x 10 cm specimen placed horizontally between the two clear acrylic sheets. The top sheet, weighing 100g, contains a 2.5 cm diameter aperture in the centre of the sheet. From a burette positioned 1 cm above the top surface of the sample a test liquid drop of 0.05 ml is placed on top of the specimen. The time needed for the drop to sink into the specimen is then determined.

Shishoo (11) also describes a horizontal wicking apparatus which consists of a test well surrounding a 5cm wide x 20cm long pad of absorbent material. A top plate with a circular aperture at one end is placed on top of the pad and a 500g load applied to the plate. A defined quantity of fluid is applied to the pad through the aperture and allowed to spread towards the other end of the material. After a fixed time, the wetted test pad is quickly cut into 5 equal lengths and the amount of fluid in each separate section determined by weighing. The test is usually repeated for different time intervals to evaluate fluid progression as a function of time. Figure 10 illustrates both test methods.

Fluid retention under pressure is evaluated be several techniques as well. Probably the simplest in centrifuging, where the presoaked material is loaded into a centrifuge tube and spun at 1500 - 1700 gravities for approximately 20 minutes. The centrifuged material is removed and weighed, then dried to constant weight and reweighed. The Water Retention Value is expressed as the weight of water retained per gram of dry absorbent. (24) This test is commonly used in the textile and pulp and paper industries (28).

As an alternative, suction can be applied to the presoaked material supported on a porous plate in a container. In each instance the imposed pressure can be adjusted to reasonably simulate end uses such as hand squeezing a sponge, a baby sitting on a wet diaper, or a patient laying on an incontinence pad.(9). George (20) describes a variation of this technique where pressure is applied above the wetted sample by means of a pressure plate.

It is evident from the foregoing that a wide variety of test procedures have been reported and are being used currently. They are all practical or pragmatic techniques designed to evaluate certain behavioural characteristics rather than basic theoretical properties of the absorbent. No standardization has yet been achieved in the testing of absorbency with the single exception of ASTM Method D-1117 for absorptive capacity of non-woven fabrics. Sample size, thickness, loading, test fluid used, support substrate all vary from lab to lab. Sample conditioning (temp/humidity) has not been specified in general.

Reproducibility of test result between labs is very poor. (9) (20) (25).

Over the period of this project, several contacts were made with representatives of the diaper industry as well as with a commercial laboratory which advertises it's ability to test the absorbency of materials. Each of these contacts was unwilling to reveal specific details about the methods and procedures which are used to evaluate the absorbency of their products. The absorbent products industry appears to be highly competitive and, consequently, rather non-communicative concerning technical aspects of these products.

In summary, then, testing of absorbent products is still an immature science which has yet to define the basic underlying theoretical principles and key parameters necessary for evaluation and consequently depends upon application-specific tests developed by individual labs.

C. SELECTION OF TEST MATERIALS

1. Sorbent Types

Sorbents may be categorized in a number of ways. The simplest categorization would be to distinguish between materials of organic and inorganic origin. Ehredt (1) categorized his sorbents as clays, cellulosics, vermiculite and polymerics. The Environmental Protection Service (2) divided sorbents into three classes in their study of oil spill sorbents as follows: natural products, modified natural products and synthetic products.

In the present study, the sorbents are divided into categories based upon their physical structure as follows:

- Foams
- Fibrous Sorbents
- Granular Sorbents

The fibrous sorbents can be further distinguished as natural fibres or synthetic fibres.

2. Sorbent Selection Criteria

A sorbent should fulfill certain basic performance and operational criteria to be acceptable for use as a packaging material in Type A radioactive packages. First and foremost, it must be readily able to pick up and retain fluids of the type present in the package. This means that some sorbents must be hydrophilic while others must be oleophilic depending upon the nature of the liquid being shipped. Secondly, the sorbent should have the following characteristics related to supply, storage, application, transportation, sorption, and disposal.

- readily commercially available at low cost
- stable in storage (long shelf life)
- light weight
- chemically stable towards acids, alkalies, oils, alcohols, chlorinated solvents, etc.
- mechanically strong and large uniform particle size (non-dusting)
- fast acting, retentive and self-wicking
- non-toxic and environmentally compatable

3. Candidate Sorbent Materials

Due to the very limited number of citations retrieved from the literature search, the selection of candidate sorbent materials had to be based upon information gathered from other sources such as previous experience with shipments of non-radioactive laboratory chemicals, information gathered from transportation emergency response teams and from users of radioactive isotopes. Based upon these sources, the following possible candidate materials were enumerated.

FOAMS:

- Polyurethane open-cell foam
- Bonded polyurethane foam chip packaging
- Expanded polystyrene packaging kernels (peanut packing)
- Polyurethane closed-cell foam
- Foamed-in-place rigid polyurethane package
- Phenol-Formaldehyde open-cell foam

FIBRES: - NATURAL

- Cellulose pulp fluff
- Absorbent paper sheet
- Straw
- Saw Dust
- Corrugated cardboard
- Cellulose pulp fluff with super absorbent polymer
- Peat Moss
- Wood shavings
- Paper towelling
- Facial tissue

FIBRES: - ARTIFICIAL

- Polypropylene/Cellulose mat (SorbX commercial product)
- Rayon sheet
- Rayon/cellulose medical sponges

GRANULAR:

- Cement kiln flue dust
- Chemsorb (commercial product)
- Vermiculite
- Cellite
- Montmorillonite Clay
- Perlite
- Pumice
- Diatomaceous Earth
- Fuller's Earth

4. Final Selection Of Test Materials

The final selection of materials was based upon a combination of factors, principally the anticipated absorbency of the materials and the practicality of use of the material as a packaging sorbent. These materials include the following:

FOAMS:

- Open-cell polyurethane foam of three different densities
- Special polyurethane foam incorporating Super Absorbent Polymer (Hydrathane made by Scotfoam Corp.)
- Polystyrene packaging kernels (not expected to be absorbent but included because of its almost universal use in packaging)

FIBRES: - NATURAL

- Cellulose pulp fluff, with and without super absorbent polymer
- Absorbent paper sheet,
- Wood shavings
- Paper towelling
- Facial tissue

FIBRES: - ARTIFICIAL

- Polypropylene/cellulose mat (SorbX made by Can-Ross Enviornmental)
- Rayon sheeting

GRANULAR:

- Cellite
- Vermiculite
- Expanded silicate mineral (Chemsorb made by Precision Labs. Inc.)
- Fuller's Earth (Travelon made by Travelon Oil Company)
- Clay absorbent (Clean Sweep)

D. LABORATORY TESTS

1. Material Composition and Structure

The materials selected for testing covered a broad range of shapes and forms, from solid blocks of foam to thin sheets of paper or tissue to loose granules or fine particles. Close-up photographs or scanning electron micrographs were obtained for each material to illustrate the physical form and dimensions of the material. These photographs and photomicrographs are included in the report as Appendix C.

The common name and principle constituents or chemical composition for each material were determined from suppliers literature or from general reference materials and are recorded along with the bulk density of the material in Table 1 on pages 31 to 33.

The bulk density was determined for each material as follows:

- for 30.5 cubic centimetre (1 cu ft) blocks of high and low density foams, the dimensions of the block were measured to the nearest millimetre (mm) and the block weighed to the nearest 5 grams (g) on a top-loading electronic balance;

- for the humidifier pad material and the Hydrathane foam pad the dimensions of the complete pad were measured to the nearest 1mm and the pad weighed to the nearest gram using a triple beam mechanical lab balance;

- for the polystyrene packing kernels, five individual kernels were selected at random and weighed to the nearest 0.1 milligram (mg), then placed individually in a 50 ml graduated cylinder filled with 40 ml of water. The kernel was forced below the water surface with a dissecting needle and the volume of water displaced (typically 4 to 6 ml) was recorded to determine the individual volumes.

- for the regular and ultra absorbent diapers, a section was cut from the centre of each diaper measuring 27 cm x 10 cm and weighed to the nearest mg on an electronic laboratory balance.

- for the absorbent paper sheet and paper towel a five ply pad was cut to 30 cm x 30 cm on an office paper guillotine and weighed on the laboratory balance to the nearest mg. The basis weight was calculated in milligrams per square centimetre (mg/cm2) for a single ply based upon this data. A series of smaller sheets, approximately 5 cm square, were also loosely layered without compression to a height of approximately 1 cm. The actual height was measured with a set of vernier calipers and the height of the stack divided by the number of plies to determine the thickness of an individual sheet in a loose stack or pile.

- for the facial tissue the same basic procedure was followed except that the tissues were not cut before layering. The dimensions of a representative sheet were measured and recorded.

- for the rayon sheet the same basic procedure was used except that each ply was cut to 20 cm x 20 cm.

- for the SorbX sheet, a single sample was cut to 20 cm x 20 cm and the thickness measured with a vernier caliper. The sample was weighed to the nearest 1 mg on the analytical balance.

- for the granular materials, including wood chips, cellite, vermiculite, Chemsorb and Fullers Earth, suitable quantities of each material were poured into preweighed 250 ml or 600 ml plastic beakers and gently shaken or tapped to compact the material lightly without applying excessive pressure to crush the material. The compacted material was topped off to the capacity mark on the beaker and then weighed to the nearest mg on the analytical balance.

Table 1. Density of Test Materials

Material	Composition	Appearance	Dimensions	Weight	Density
FOAMS					
Yellow Foam	High density polyurethane open-cell foam; Grade HR 35	Yellow foam small, visible cell pores	30.5 cm cube	1350 g	0.047 g/cm3
White Foam	Low density polyurethane open-cell foam; Grade 1112	White foam small visible cell pores	30.5 cm cube	495 g	0.017 g/cm3
Humidifier Pad	Medium density reticulated polyurethane	Yellow-Gold foam with very porous open structure	60x20x2 cm	70 g	0.029 g/cm3
Hydrathane	High density reticulated polyurethane foam with impregnated SAP	Blue foam small visible pores	30x31.5x4 cm	175 g	0.047 g/cm3
Polystyrene Kernels	Expanded Polystyene foam	White smooth skin various shapes	4 to 6 ml volume per kernel	46 to 77 mg per kernel	0.012 g/cm3

Table 1.(cont) Density of Test Materials

Material	Composition	Appearance	Dimensions	Weight	Density
NATURAL FIBRES					
Regular Huggies	Cellulose Pulp fluff	White fibrous pulp mass	27x10x0.5 cm	17.7440 g	0.1310 g/m3
Ultra Pampers	Cellulose Pulp Fluff with SAP	White fibrous mass with individual small round beads throughout	27x10x1 cm	24.358 g	0.090 g/cm3
Absorbent Paper Sheet	Cellulose fibre web with polyethylene film backing	White,thin paper sheet; textured	30x30 cm x5 ply	37.4630 g Basis Weight = 0.0083 g/cm2 Thickness = 0.038 cm/sheet	0.271 g/cm3
Paper Towel	Cellulose fibre web	White thin paper sheet; textured	30x30 cm x5 ply	12.1272 g Basis Weight = 0.0035 g/cm2 Thickness = 0.0388 cm/sheet	0.102 g/cm3
Facial Tissue	Cellulose fibre web	Beige, thin tissue, 2 ply per tissue	21.7x19.2 x5 ply	6.6367 g Basis Weight = 0.0032 g/cm2 Thickness = 0.0142 cm/sheet	0.180 g/cm3
Wood Chips	Softwood chips	Beige to tan colour, thin wood chips	600 ml	40.030 g	0.067 g/cm3

Table 1.(cont) Density of Test Materials

Material	Composition	Appearance	Dimensions	Weight	Density
ARTIFICIAL FIBRES					
SorbX	65% polypropylene 35% cellulose fibres	White fibrous matt	20x20 x0.488 cm	13.996 g Basis Weight = 0.035 g/cm2 Thickness = 0.488 cm/sheet	0.0717 g/cm3
Rayon Sheet	Rayon fibres	White, thin sheet non-woven	20x20 cm x5 ply	2.032 g Basis Weight = 0.001 g/cm2 Thickness = 0.0223 cm/sheet	0.0444 g/cm3
GRANULAR					
Cellite	Flux-calcined diatomaceous earth	White fluffy powder fine particles	250 ml	107.223 g	0.429 g/cm3
Vermiculite	Expanded plates of hydrous magnesium aluminum iron silicate	Tan coloured light particles, layered	600 ml	57.762 g	0.096 g/cm3
Fullers Earth	Amorphous, hydrous Aluminum Silicate	Light tan coloured granules, various sizes	250 ml	154.260 g	0.617 g/cm3
Chemsorb	Expanded amorphous silicate	White fluffy powder, very fine particles	600 ml	35.997 g	0.060 g/cm3

2. Absorbency

The absorbency of the test materials was determined in one of two ways. For the foams and fibres, a preweighed sample of selected dimensions was immersed directly into a 1 litre glass beaker containing 1 litre of distilled water. The sample was submerged just below the surface of the water for 1 minute, then removed and suspended above the beaker to drain. The drain time had to be varied depending upon the nature of performance of each test material. After a suitable drain time, the sample was reweighed in a pretared paper cup on the analytical balance and the weight gain divided by the dry sample weight to determine the absorbency in grams of liquid absorbed per gram of absorbent material (g/g). The immersion/ drain/reweigh cycle was repeated and any additional water gain was recorded for each repetition of the cycle, until no further gain was noted. The actual dimensions of the sample block as well as the immersion and drain times are included in table 2.

The diaper materials were found to swell considerably when wet and had insufficient wet strength to hold together when suspended to drain. Therefore an open wire basket was fabricated of 7 mesh galvanized steel hardware cloth. The basket was 6.5 cm x 6.5 cm square with a 2.0 cm high sidewall, and was equipped with a harness of nylon monofilament line extending from each of the four corners to a central apex in order to suspend it in the 1 litre beaker of water. Square sections of diaper material were cut and placed without compression into the wire basket, which was then immersed just below the surface of the water in the beaker for one minute, then removed and allowed to drain freely for 20 minutes before reweighing. The initial trials with this technique used 6 cm x 6 cm squares of material just slightly smaller than the dimensions of the basket itself. However, the swelling and expansion of the material when wet caused the diaper material to overflow the basket and fall into the beaker. Therefore, the size of the dry pad was gradually reduced by trial and error until it was found that a 3 cm x 3 cm square of dry material would still remain inside the basket upon swelling to it's full wet dimensions. The wire basket and test set-up are illustrated on pages C-9 and C-11 of Appendix C.

For granular materials, where immersion and recovery were not practical, a modification of the capillary absorbency test was used. A 30 ml capacity glass Buchner funnel with a coarse glass frit was clamped to a burette stand and connected with a length of flexible plastic tubing to a 50 ml glass burette filled with distilled water. The height of the funnel was adjusted relative to the water level in the burette so that the frit surface was just wetted but no water lay on top of the frit. Approximately 20 ml of granular material was weighed out into pretared paper cups, transferred to the funnel and gently tapped to compact the material. The initial volume of water in the burette was recorded, then the funnel was lowered so that water flowed from the burette into the funnel. When the water level just rose above the surface of the granular material, the burette stopcock was closed to shut off the flow of water and the stopwatch started to time the immersion. At the end of one minute, the burette stopcock was opened, the funnel raised and the material allowed to drain. By watching the rate of increase of water level in the burette, it was possible to determine an adequate drain time which was found to be 10 minutes. As the rate of rise of the water level in the burette slowed, the filter position was adjusted so that the top of the glass frit was level with the meniscus in the burette. After sufficient drain time, the final reading of the burette was recorded to determine the volume of water absorbed by the sample. This volume was converted to mass of water by multiplying by the specific gravity of water, determined by delivering 50 ml of water from the burette into a preweighed beaker and reweighing. The specific gravity of water at the laboratory room temperature was 0.9899 gm/ml. This immersion/drain cycle was repeated successively until no further uptake of water was noted from the burette.

For each sorbent, a minimum of three samples of the material were tested and the mean absorbency for the first 1 minute immersion is reported in Table 2 on the following page as well as the ultimate absorbency and the number of immersions required to reach that value.

Table 2:

Absorbency Test Results

Material	Absorbency 1 Min Mean (g/g)	Absorbency 1 Min S.D. (g/g)	Absorbency Ultimate Mean (g/g)	Absorbency Ultimate S.D. (g/g)	No of Immersions	Sample Size	Dry Weight	N	T(i) (min)	T(d) (min)
FOAMS:										
Yellow foam	4.04	2.39	7.21	1.70	2 to 5	5x5x5 cm	approx. 7 g	3	1	20
White foam	7.83	1.65	19.7	1.24	3 to 4	5x5x5 cm	approx. 2 g	3	1	20
Hydrathane	2.88	0.36	17.6	1.24	7	2.5x2.5x4 cm	approx. 1 g	3	1	20
Humidifier Pad	5.81	0.36	5.86	0.30	2	7x7x2 cm	approx. 3 g	3	1	20
Polystyrene	1.77	0.88	1.77	0.88	2	4 to 6 ml	46 to 77 mg	3	1	20
FIBRES, NATURAL:										
Regular Diapers	20.4	0.57	20.4	0.57	2	3x3x0.5 cm	approx. 1.6 g	3	1	20
Ultra Diapers	40.6	1.01	57.0	4.65	3	3x3x1 cm	approx. 1.4 g	3	1	20
Absorbent Paper	6.88	0.51	7.00	0.50	2 to 4	7.5x7.5 cm x1ply	approx. 0.5 g	5	1	5
Paper Towel	9.36	2.01	9.36	2.01	2	6x6 cm x5ply	approx. 1 g	3	1	5
Facial Tissue	8.78	1.62	8.78	1.62	2	9x9 cm x5ply	approx. 1 g	5	1	5
Wood Chips	2.58	0.28	2.88	0.30	2 to 3	36 ml	approx. 2.4 g	4	1	10
FIBRES, ARTIFICIAL:										
SorbX	22.2	3.90	22.2	3.90	2	3.5x3.5 cm x1ply	approx. 0.5 g	3	1	20
Rayon	10.3	1.03	11.7	2.59	2 to 3	7x7 cm x1ply	approx. 0.4 g	3	1	5
GRANULARS:										
Cellite	2.06	0.02	2.10	0.02	2	approx. 20 ml	approx. 10 g	3	1	10
Vermiculite	3.44	0.12	3.55	0.11	2 to 3	approx. 30 ml	approx. 3 g	3	1	10
Fuller's Earth	0.98	0.10	0.98	0.10	2	approx. 10 ml	approx. 7 g	3	1	10
Chemsorb	9.43	1.18	9.57	1.13	2	approx. 25 ml	approx. 1.5 g	5	1	10
Clean Sweep	0.71	0.19	0.86	0.18	2 to 3	approx. 10 ml	approx. 7 g	3	1	10

S.D. = Standard Deviation, T(i) = Immersion Time, T(d) = Drain Time, N = No. of Replicate Samples

3. Compression

The effect of compression of the sorbent on its absorbency was determined using a modification of the capillary absorbency testing apparatus. The Buchner funnel of the apparatus was equipped with a screw compression device consisting of an 8.0 cm long machine screw with a 3.2 cm diameter flat disc attached to the end and a nut positioned half-way up the screw stem. The device was clamped above the Buchner funnel by means of a hose clamp around the nut, so that the stem could move up and down freely within the Buchner funnel. The complete apparatus is illustrated in the attached photograph (See Appendix C, page C-12).

In using the apparatus, the position of the burette was first adjusted so that the water level in the funnel just reached the top surface of the glass fit. A preweighed amount of sorbent material was added to the Buchner funnel to a height of 3.0 to 3.5 cm above the glass frit. The funnel was then lowered relative to the water level in the burette and the sorbent material immersed for 1 minute, then the funnel was raised again and the sorbent material allowed to drain for 10 minutes until no further change in water level of the burette was noted. The decrease in water volume in the burette was recorded in order to determine the absorbency in the uncompressed state.

The height of the uncompressed, wet material in the column was determined and the appropriate heights for compressions of 20%, 40% and 60% calculated and marked on the outer surface of the funnel. The screw compression head was then positioned over the absorbent material sample and adjusted until the compression disc just touched the top of the sorbent material. The sorbent material was then compressed 20% by turning the screw head down to the first mark on the funnel and the burette raised relative to the funnel in order to re-immerse the compressed material for 1 minute.

After draining was complete the change in volume of the water in the burette was recorded again. The regain in water volume in the burette was taken as the measure of reduced absorbency under 20% compression. The procedure was repeated twice more at 40% and 60% compression as well to determine the absorbent capacity at 0%, 20%, 40% and 60% compression.

The data are summarized in the following table.

Table 3: Compression Test Results

Mean 1-Minute Absorbent Capacity (g/g) and
Percent Reduction in Absorbency from Uncompressed State

Material	Uncompressed	20% Compression		40% Compression		60% Compression	
	Capacity	Capacity	Reduction	Capacity	Reduction	Capacity	Reduction
	Mean (Std Dev)	Mean (Std Dev)		Mean (Std Dev)		Mean (Std Dev)	
FOAMS:							
Yellow foam	4.05 (0.549)	3.25 (0.168)	-19.8%	2.66 (0.102)	-34.3%	2.28 (0.311)	-43.7%
White foam	13.8 (3.018)	10.2 (3.090)	-26.0%	8.35 (3.015)	-39.6%	6.46 (2.832)	-53.3%
Hydrathane	13.6 (1.651)	11.9 (1.551)	-12.2%	10.5 (1.364)	-22.4%	8.78 (0.830)	-35.2%
FIBRES, NATURAL:							
Regular Diapers	8.55 (0.720)	7.57 (0.345)	-11.4%	6.75 (0.410)	-21.1%	5.03 (0.595)	-41.2%
Ultra Diapers	13.4 (1.189)	12.2 (0.833)	-9.2%	(1)		(1)	
Paper Towel	4.49 (0.485)	4.34 (0.534)	-3.3%	4.11 (0.521)	-8.4%	3.27 (0.460)	-27.2%
Facial Tissue	4.82 (0.700)	4.25 (0.491)	-11.9%	3.79 (0.231)	-21.4%	2.81 (0.206)	-41.7%
FIBRES, ARTIFICIAL:							
SorbX	13.8 (1.497)	13.8 (1.497)	(2)	12.2 (1.037)	-11.7%	8.59 (1.120)	-37.8%
Rayon	5.35 (0.864)	4.51 (0.227)	-15.6%	3.76 (0.164)	-29.6%	2.70 (0.317)	-49.4%
GRANULARS:							
Vermiculite	3.20 (0.663)	2.98 (0.633)	-6.6%	(3)		(3)	
Chemsorb	8.91 (0.303)	7.88 (0.509)	-11.5%	6.14 (0.838)	-31.1%	(4)	
Fuller's Earth	0.98 (0.957)	(5)		(5)		(5)	

(1) - Ultra diapers would not compress beyond approximately 30% of original height
(2) - SorbX pads self-compress when wet by approximately 20% of their dry height
(3) - Vermiculite would not compress beyond approximately 20% compression
(4) - Chemsorb Powder would not compress beyond approximately 40% compression
(5) - Fuller's Earth consists of non-compressible clay granules

4. Humidity Effects

Samples of each type of sorbent material were preconditioned at 21 C and various levels of relative humidity for a period of at least 2 days before determining the absorbency of each sample based upon a 1 minute immersion. The minimum 2 day conditioning period is a departure from the original planned 7 day conditioning period but the results of the evaporation tests which were completed before these tests were begun demonstrate that the absorbent materials reach virtual equilibrium with the surrounding atmosphere within the first 24 hours. Therefore a 2 day equilibration time was considered sufficient to conduct the tests.

Groups of three samples for each sorbent were placed inside 25 cm diameter Nalgene vacuum dessicators, either directly on the ceramic plate or in small paper cups. A variety of saturated salt solutions were placed in glass petri dishes in the base of each dessicator to generate different relative humidity levels. A small battery-operated relative humidity indicator (RH Pen) was placed inside each dessicator overnight to determine the actual relative humidity in the dessicator chamber. The RH Pen had been precalibrated against an electronic wetted-wick psychrometer at ambient temperature and humidity (21 C and 20% RH) and found to give good agreement. The dessicants used and the relative humidities reached were as follows:

Indicating Drierite	5%
Ambient Lab (mid-winter)	15%
Calcium Chloride Hexahydrate	30%
Ammonium Nitrate	60%
Sodium Carbonate Decahydrate	79%

A sixth set of sorbent samples were conditioned at 21 C and 50% relative humidity in a controlled environment chamber (Tenney Jr Model TH-JR), since efforts to generate a 50% RH environment in the dessicators were unsuccessful.

The results of the 1 minute absorption capacity test on each of these materials in summarized in the table on the next page. The absorbency testing was all conducted using water as the test fluid.

Table 4: **Humidity Test Results**

1-Minute Absorbent Capacity - g/g
mean of 3 samples
(Standard Deviation)

Material	5% RH	15% RH	30% RH	50% RH	60% RH	79% RH
FOAMS:						
Yellow foam	2.16	2.45	3.40	8.22	5.32	4.21
	(0.43)	(0.97)	(0.76)	(3.42)	(0.22)	(0.82)
White foam	5.39	6.23	7.83	5.29	9.22	11.1
	(0.02)	(2.70)	(0.68)	(1.16)	(1.57)	(2.72)
Hydrathane	3.29	3.46	2.98	3.92	3.24	3.65
	(0.26)	(0.69)	(0.44)	(1.06)	(0.31)	(0.49)
FIBRES, NATURAL:						
Regular Diapers	19.1	25.5	17.6	18.6	18.9	18.3
	(1.84)	(4.71)	(1.08)	(0.27)	(1.49)	(0.42)
Ultra Diapers	34.2	48.4	37.0	27.2	31.0	35.1
	(4.12)	(7.12)	(3.15)	(3.16)	(5.65)	(4.01)
Paper Towel	6.82	5.01	7.07	7.15	6.75	6.47
	(0.12)	(2.36)	(0.15)	(0.13)	(0.15)	(0.23)
Facial Tissue	7.62	6.08	7.29	6.56	6.28	6.89
	(1.13)	(0.14)	(1.68)	(0.44)	(1.11)	(0.33)
FIBRES, ARTIFICIAL:						
SorbX	16.4	15.3	16.4	14.5	18.2	15.6
	(1.25)	(0.32)	(1.28)	(0.57)	(2.03)	(1.44)
Rayon	6.93	6.25	7.05	6.60	6.85	6.43
	(0.12)	(0.18)	(0.21)	(0.03)	(0.09)	(0.09)
GRANULARS:						
Vermiculite	4.41	3.44	3.41	3.31	3.41	3.69
	(0.05)	(0.12)	(0.43)	(0.19)	(1.68)	(0.07)
Chemsorb	8.58	9.43	10.2	8.60	8.31	7.55
	(0.80)	(1.18)	(0.34)	(1.45)	(0.24)	(1.78)
Fuller's Earth	(1)	(1)	(1)	(1)	(1)	(1)

(1) - Sample of Fuller's Earth was not received in time for inclusion in this test.

Figure 11-1: Humidity Effects

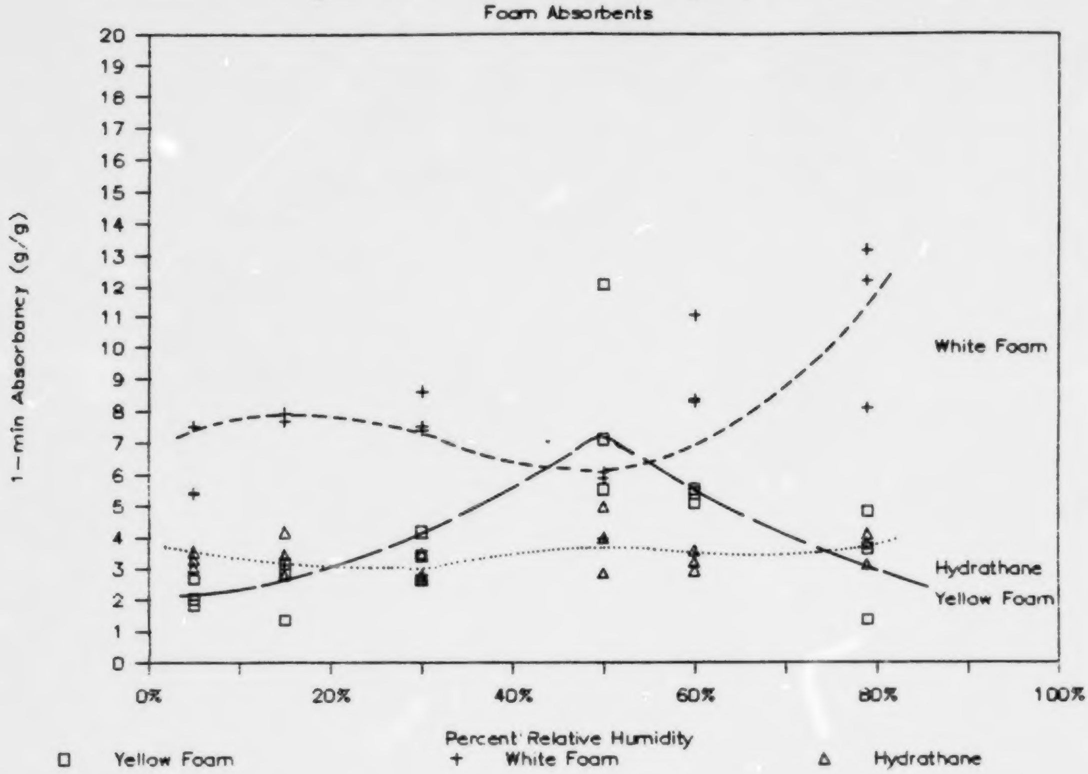


Figure 11-2: Humidity Effects

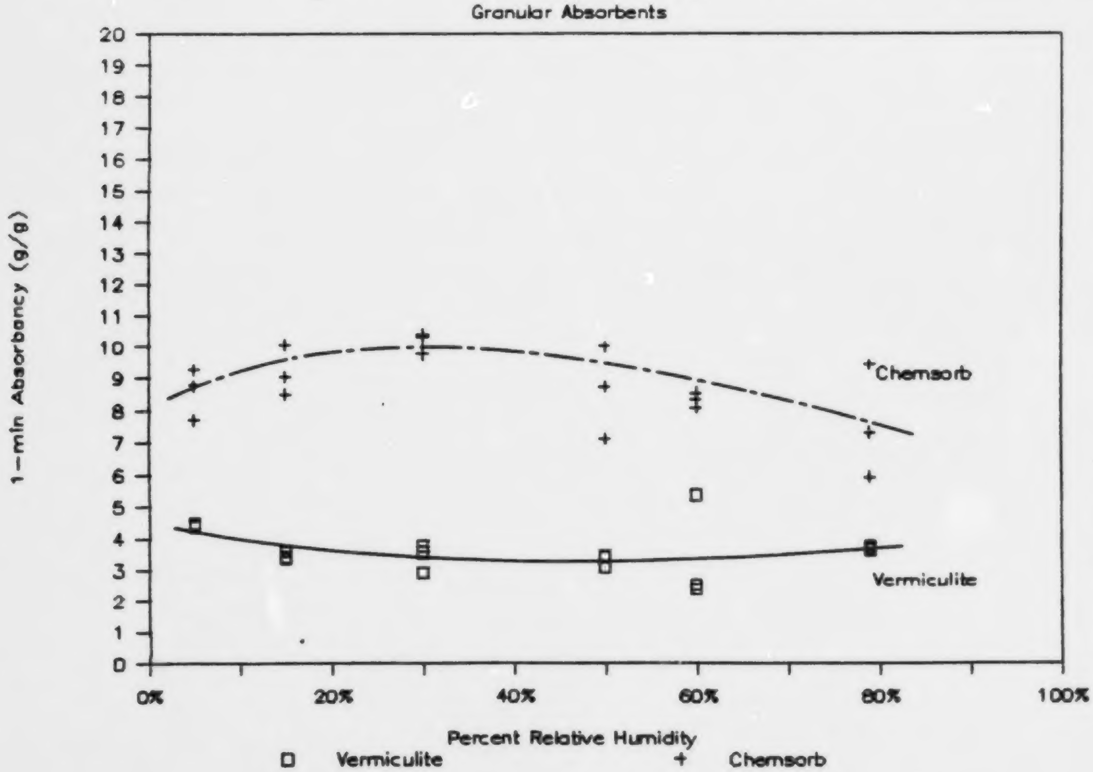


Figure 11-3: Humidity Effects

Natural Fibre Absorbents

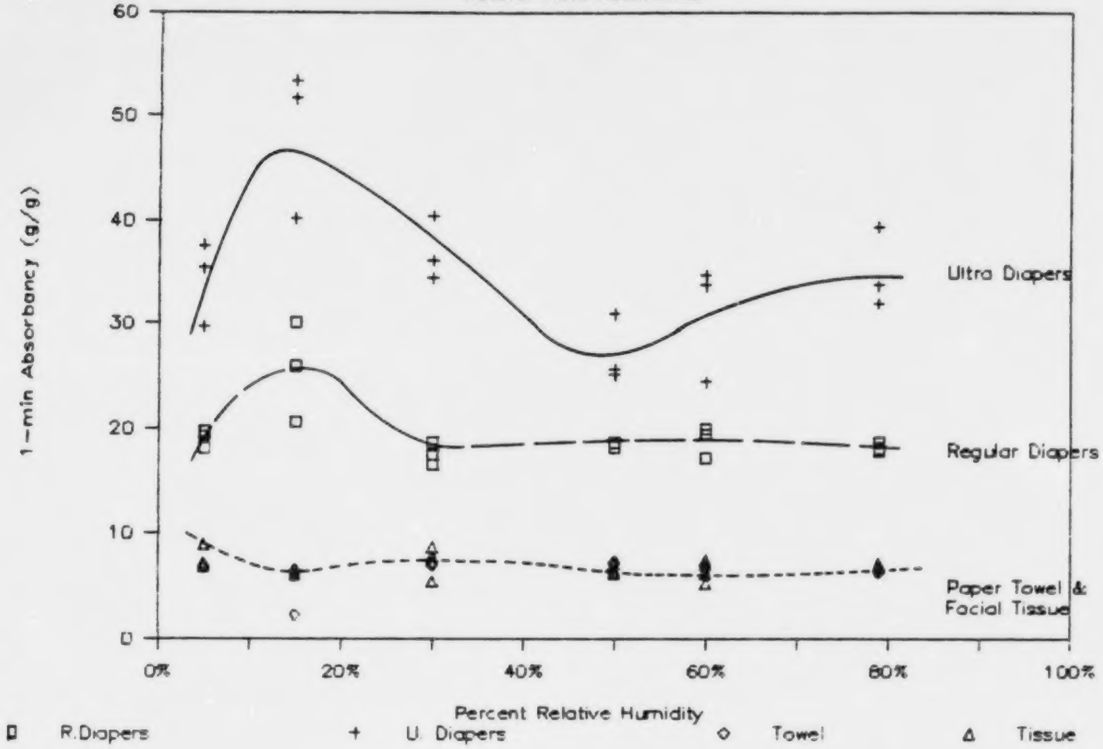
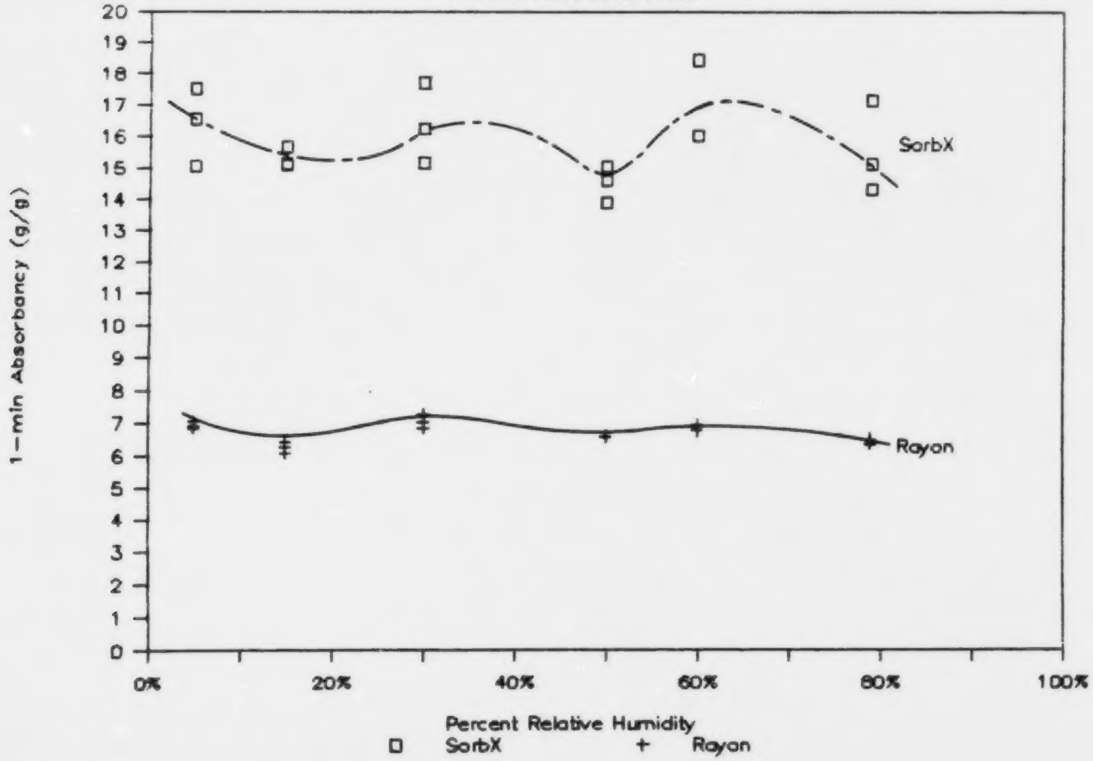


Figure 11-4: Humidity Effects

Artificial Fibre Absorbents



5. Seepage

In order to determine the amount of liquid which would potentially seep out of an absorbent material after having absorbed the liquid from a broken container, the following seepage test was conducted.

Three representative samples of each type of absorbent material were weighed on an analytical balance and the weight used to calculate the volume of water necessary to load each sample to 50% of its absorbent capacity. The samples were loaded into 50 ml capacity polycarbonate centrifuge tubes which were equipped with a 25 mm diameter galvanized steel screen disk (7 mesh) at the point in the centrifuge tube where it begins to taper down to a point. The centrifuge tubes were precalibrated with volume markings down to as little as 0.5 ml on the tip of the cone.

Each sample was loaded into the centrifuge tube dry, then the required volume of water was dispensed from the burette onto the top surface of the sorbent. The samples were allowed to soak up or absorb the water for a period of 10 minutes while the centrifuge tubes were held vertically in a rack. Any liquid which drained through the material was retained in the base of the centrifuge tube and the volume of collected water after the 10 minute standing period was recorded. With the wide range of absorbencies used, water volumes loaded to the tubes ranged from 2.8 to 57.0 ml.

This method worked well with the fibrous materials and with the granular materials except that a pre-wetted 25mm glass fibre filter was placed on top of the screen in the centrifuge tube in order to retain the granular material, particularly the very small Chemsorb particles. With the foam materials, including the Hydrathane foam, it was noted that the water did not readily absorb into the foam and would remain on top of the foam for more than 10 minutes without being appreciably absorbed. The method finallu adopted with the foams in order to load them with water to 50% of their capacity was to dispense the required volume of liquid into a glass petri dish, then compress the foam sample, place it in contact with the petri dish and allow it to expand and soak up the water. The wetted foam was then carefully placed into the centrifuge tube with as little handling and compression as possible.

Seepage tests were carried out in triplicate with each of the test sorbents. No seepage was recorded for any of the fibrous or granular materials nor for the Hydrathane but one of the three samples of white foam lost 0.5ml of water and two of the three samples of yellow foam lost 1.0 and 1.5ml of water respectively. The results are given in the table on the following page.

Table 5: **Seepage Test Results**

Material	Trial	Weight	Water Added	Seepage Volume
FOAMS:		(grams)	(mls)	(mls)
Yellow foam	1	1.3096	5.9	1.0
	2	1.3980	6.3	1.5
	3	1.3598	6.1	0.0
White foam	1	0.3096	3.0	0.0
	2	0.3898	3.8	0.0
	3	0.3727	3.6	0.5
Hydrathane	1	0.6316	5.5	0.0
	2	0.7360	6.4	0.0
	3	0.7153	6.2	0.0
FIBRES, NATURAL:				
Regular Diapers	1	1.2515	12.7	0.0
	2	1.2285	12.4	0.0
	3	1.6611	16.8	0.0
Ultra Diapers	1	1.2948	36.5	0.0
	2	1.9260	54.3	0.0
	3	1.2144	57.0	0.0
Paper Towel	1	0.7470	3.5	0.0
	2	0.7914	3.7	0.0
	3	0.8224	3.8	0.0
Facial Tissue	1	1.1238	4.1	0.0
	2	0.7641	2.8	0.0
	3	1.2112	4.5	0.0
FIBRES, ARTIFICIAL:				
SorbX	1	0.6124	6.7	0.0
	2	0.5653	6.2	0.0
	3	0.6185	6.8	0.0
Rayon	1	1.0954	6.3	0.0
	2	1.1611	6.7	0.0
	3	1.0220	5.9	0.0
GRANULARS:				
Vermiculite	1	3.2930	5.6	0.0
	2	3.2352	5.5	0.0
	3	3.4765	5.9	0.0
Chemsorb	1	1.4807	7.8	0.0
	2	1.4750	7.8	0.0
	3	1.1999	6.3	0.0

6. Wicking

The ability of a sorbent material to quickly draw liquid into its internal structure from a surface contact with the liquid was evaluated by means of a wicking test. Each sorbent material was tested in triplicate using distilled water to which a few drops of food colouring (green, blue, or red) were added to aid in observing the progression of liquid up the length of the sorbent column. Wicking columns were built from 2.5 cm i.d. clear acrylic plastic columns approximately 33 cm high, with a plastic mesh screen (approx 1 mm openings) glued with epoxy adhesive to the bottom end of the column. Hash marks were placed on the outside surface of the column at 5 mm intervals for a distance of 20 cm up from the screened end of the columns. These columns were held vertically in a laboratory clamp stand with the screened end immediately above a standard glass petri dish containing the coloured water.

Thin strips of fibrous and foam materials, 30 cm in length were cut and suspended inside the column. The fibrous materials had to be supported in this way because they did not have sufficient wet strength to withstand being suspended without support. With the granular materials, a prewetted 2.5 cm glass fibre filter was placed into the column first, then the column was packed to a height of more than 20 cm with the granular material and gently tapped to lightly compact the material. A longer column (60 cm) had to be constructed for the Cellite because of it's unique wicking ability.

The wicking process was begun by lowering the packed column until it just touched the surface of the water in the petri dish while at the same time starting the digital stopwatch. The progression of the liquid up the column was recorded at 30 second intervals over a period of up to 15 minutes until vertical wicking ceased. At the same time, the lower edge of the column was maintained in contact with the surface of the water by periodically adding distilled water from a plastic squeeze bottle as required.

The results of the wicking tests are summarized in the table on the following page and illustrated in the attached charts.

Table 6: Wicking Test Results

Material	Trial	Height After 1 Min (cm)	Final Height Reached (cm)	Time to Reach Final Height (min)
FOAMS:				
Yellow foam	1	0.0	0.0	Non-wicking
White foam	1	0.0	0.0	Non-wicking
Hydrathane	1	0.0	0.0	Non-wicking
FIBRES, NATURAL:				
Regular Diapers	1	9.0	10.3	1.5
	2	11.5	11.8	2.5
	3	10.0	12.3	4.0
Ultra Diapers	1	6.5	8.0	3.5
	2	7.0	9.5	6.0
	3	7.0	8.0	2.5
Paper Towel	1	5.3	6.0	2.5
	2	5.0	8.0	4.5
	3	5.5	9.0	5.0
Facial Tissue	1	6.0	10.0	4.5
	2	6.0	9.5	4.5
	3	6.5	9.8	4.0
FIBRES, ARTIFICIAL:				
SorbX	1	5.0	5.5	1.5
	2	5.0	5.0	0.5
	3	5.0	5.0	0.5
Rayon	1	0.0	0.0	Non-wicking
GRANULARS:				
Vermiculite	1	3.5	4.0	1.5
	2	3.5	4.0	2.5
	3	3.0	3.5	2.5
Chemsorb	1	7.0	17.4	15.5
	2	6.5	17.0	19.0
	3	6.0	17.0	18.5
Fuller's Earth	1	2.0	2.3	3.0
	2	2.0	2.5	2.0
	3	1.9	2.2	3.0
Cellite	1	6.0	30.9	54.5

Figure 12-1: Wicking Effects

Granular Absorbents

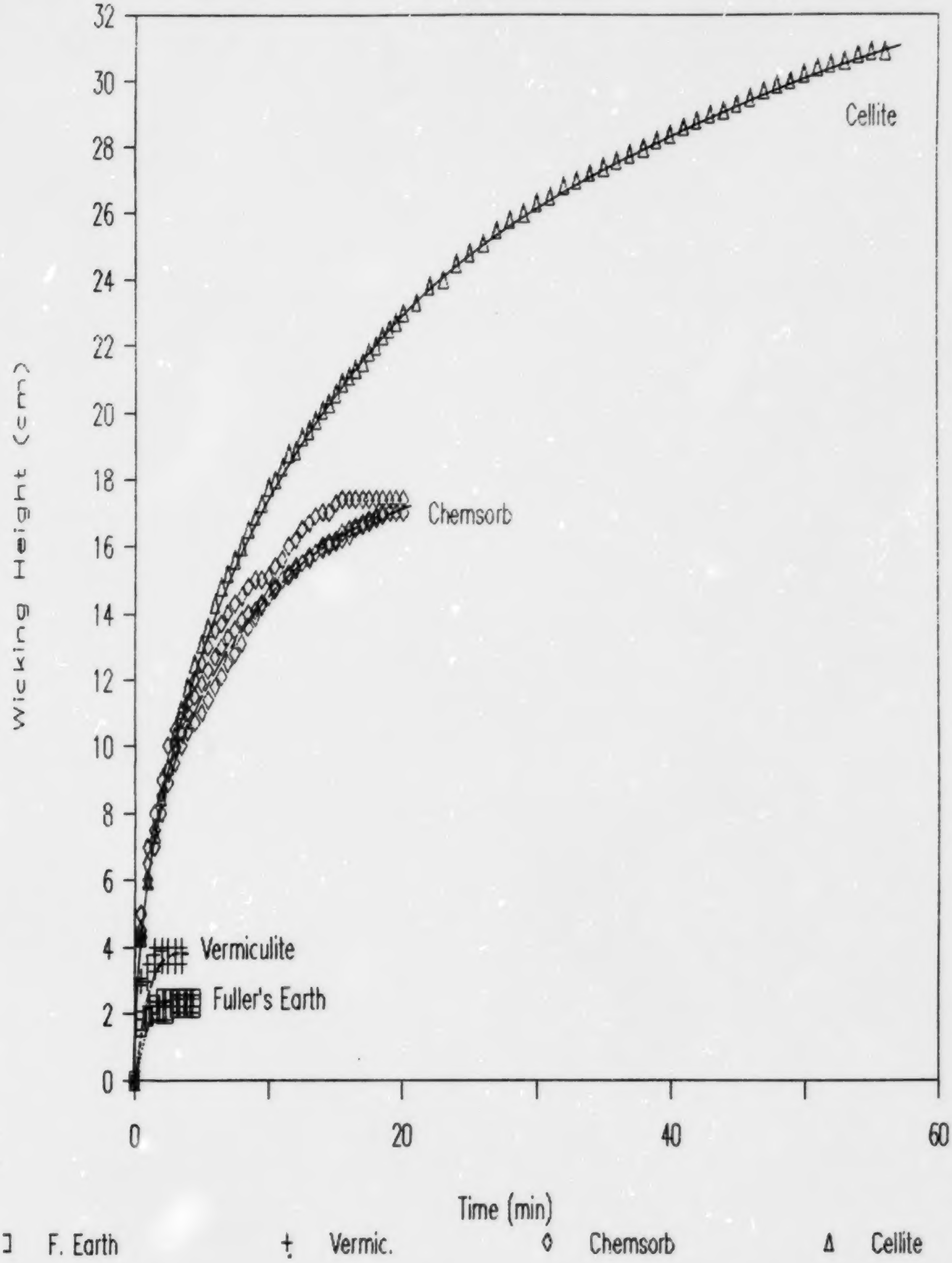
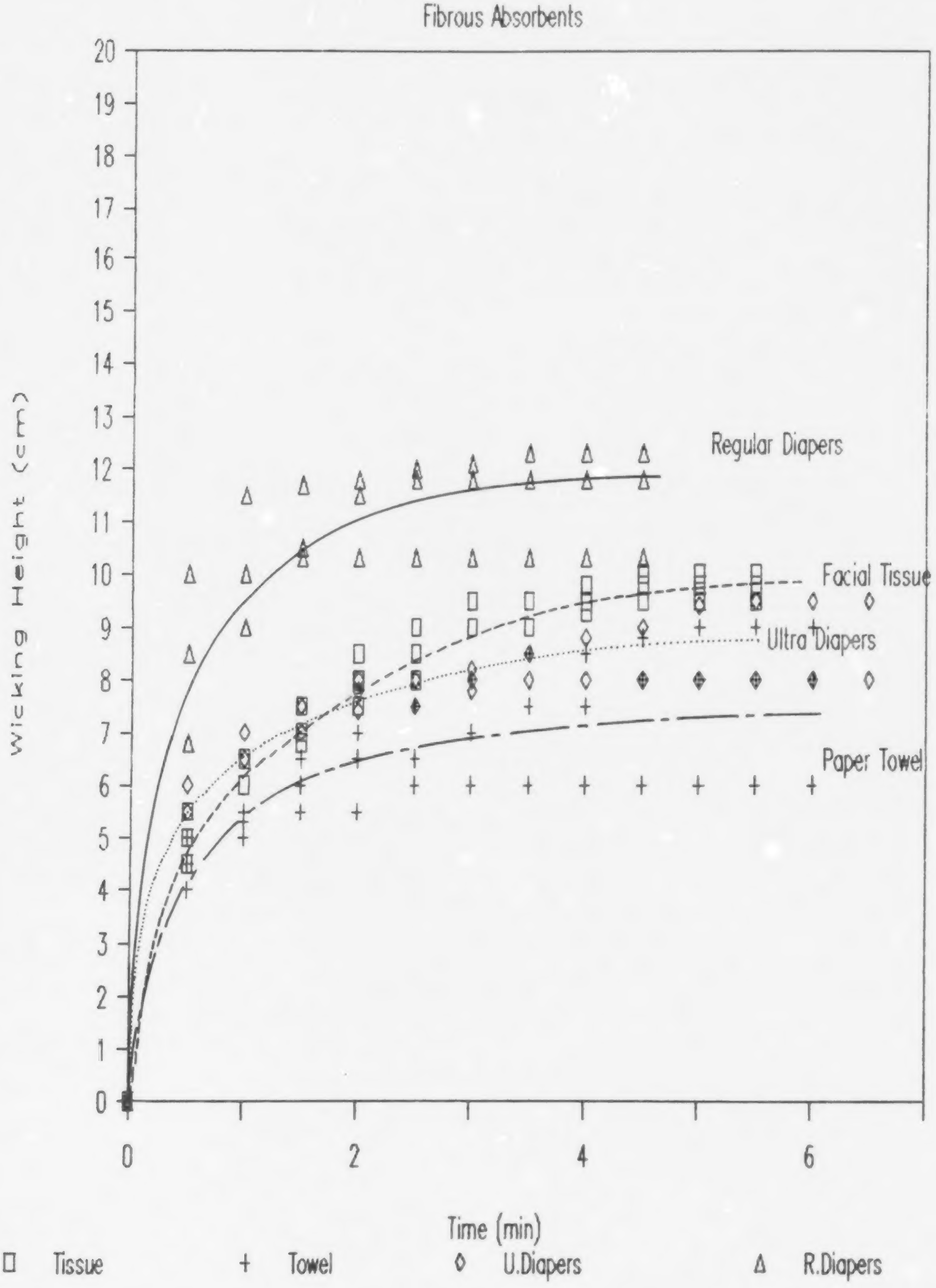


Figure 12-2: Wicking Effects



7. Evaporation

In order to establish the evaporation rate of water from the surface of the various test materials, triplicate samples of each sorbent were conditioned for 24 hours at 21 C and 50 percent relative humidity. The samples were then preweighed in the dry state in their individual petri dishes, loaded with distilled water from a 50 ml burette to 50% of their absorption capacity and reweighed to establish the initial wet weight.

The samples were then placed in a controlled environment chamber (Tenney Jr Model TH JR) and held at 21 C and 50 percent relative humidity over the following 8 day period. At approximately 24 hour intervals, the samples were removed and reweighed to determine moisture loss.

Due to difficulties experienced in obtaining a sample of the Fuller's Earth granular clay absorbent and temporarily running out of SorbX material, these two materials were not available for test until after the evaporation test had been completed. They were preconditioned and tested seperately therefore using a shortened test cycle of 2 days only. The shorter test cycle was considered adequate since the first test set had demonstrated that 90% or more of the moisture in the sorbent was lost within the first 24 hours after loading the materials.

The results of all the evaporation tests are summarized in the attached Table 7 on the following page. The results for the regular diapers and ultra-absorbent diapers are plotted in the attached chart.

The results indicate that the loss of absorbed water by evaporation is very rapid and that the majority of the absorbed water is lost within the first day. The presence of super absorbent polymer in the Hydrathane foam and in the ultra diapers reduces the evaporation rate somewhat for these two products. The initial dry weight of sample 1 for the regular diapers would appear to have been recorded incorrectly since the evaporation loss reached 81.8% within twenty-four hours and remained stable at that value for the remaining seven days while the other two samples of the same material lost essentially 100% of their absorbed water within the first 24 hours.

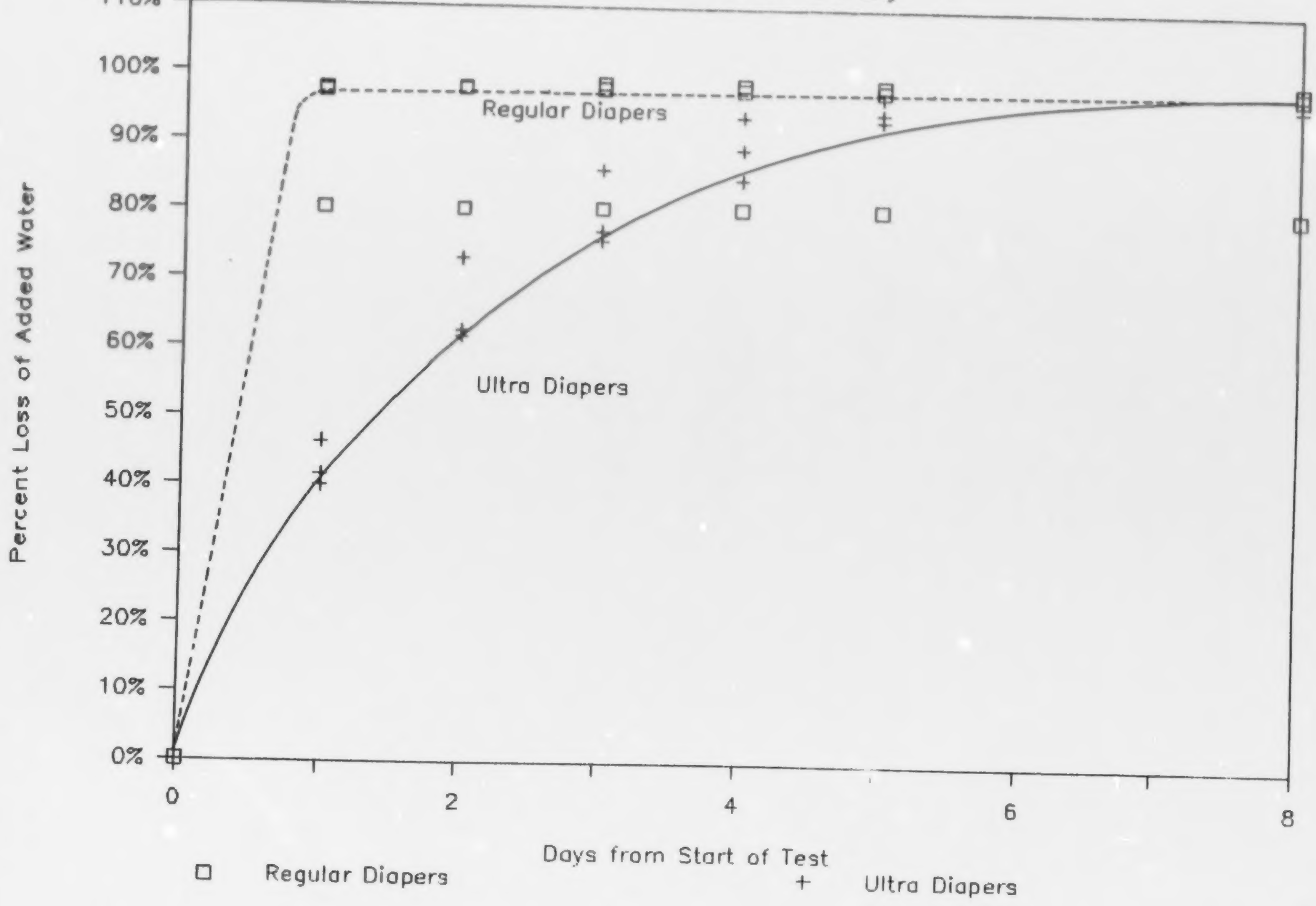
Table 7: Evaporation Test Results

Material	Trial	Dry Weight (grams)	Water Added (grams)	Moisture Loss - % 24 Hr	Moisture Loss - % 8 Day
FOAMS:					
Yellow foam	1	2.0258	9.0081	89.5%	93.6%
	2	1.8790	8.3152	78.0%	94.1%
	3	2.2093	9.8000	82.0%	93.8%
White foam	1	1.0573	10.1960	78.4%	93.3%
	2	1.2395	11.9778	91.5%	95.5%
	3	1.1448	11.0869	82.2%	94.7%
Hydrathane	1	1.0995	9.5030	73.5%	87.3%
	2	1.0589	9.1071	80.1%	93.5%
	3	1.3258	11.3839	87.9%	87.7%
FIBRES, NATURAL:					
Regular Diapers	1	0.5620	5.6424	81.8%	81.9%
	2	0.5010	5.0485	98.8%	99.6%
	3	0.5695	5.7414	29.4%	100.2%
Ultra Diapers	1	1.5411	43.0607	47.3%	99.9%
	2	1.6025	44.7435	40.8%	100.0%
	3	1.8006	50.2869	42.5%	98.4%
Paper Towel	1	1.2874	5.9394	99.9%	100.0%
	2	1.3370	6.1374	99.2%	99.6%
	3	1.3503	6.2364	100.6%	101.2%
Facial Tissue	1	1.2257	4.4546	98.7%	99.5%
	2	1.4129	5.1475	98.6%	99.2%
	3	1.3872	6.2871	99.0%	99.4%
FIBRES, ARTIFICIAL:					
SorbX	1	0.5242	5.8526	99.9%	99.9%*
	2	0.6432	7.1401	100.0%	100.0%*
	3	0.5085	5.7297	99.9%	100.0%*
Rayon	1	0.5570	3.4386	99.6%	100.0%
	2	0.6102	3.5021	100.9%	101.3%
	3	0.5013	2.9274	99.3%	99.7%
GRANULARS:					
Vermiculite	1	3.3544	5.6424	81.9%	82.0%
	2	3.2719	5.4445	99.2%	99.3%
	3	2.9892	5.0485	98.9%	101.5%
Chemsorb	1	1.7455	9.1071	96.9%	100.5%
	2	1.0678	5.5434	99.0%	105.0%
	3	1.3616	7.6222	97.7%	99.5%
Fuller's Earth	1	14.6366	7.0323	98.0%	98.1%*
	2	17.8611	9.0247	97.6%	97.7%*
	3	20.2304	9.9607	97.6%	97.7%*

* - Test conducted for 2 days only

Figure 13: Evaporation from Wet Sample

21 C and 50% Relative Humidity



8. Squeeze Tests

The ability of the various sorbent materials to retain absorbed liquid under compression was tested by means of a squeeze test. Three preweighed samples of each sorbent material were placed into 50 ml polypropylene centrifuge tubes containing an 8 mesh galvanized steel screen at the neck of each tube as well as a prewetted glass fibre filter for the fine granular materials. The absorbent was then loaded with a sufficient volume of distilled water from the 50 ml burette to equal 50% of the absorbent capacity of the material. The wetted absorbents were left standing for 10 minutes to thoroughly absorb and distribute the water. The centrifuge tube was clamped in a laboratory stand and a screw compression device positioned above the tube. This screw compression device was essentially identical to that described for the compression test except that the flat compression disk was smaller (2.5 cm diameter) in order to fit into the centrifuge tube.

The uncompressed height of the material was noted and then the material was compressed vertically to 50% of this height while the horizontal dimensions remained unchanged. Any liquid draining from the sorbent material under compression was retained in the bottom of the centrifuge tube and the volume of the collected liquid determined from the imprinted volume calibration marks on the side of the centrifuge tube.

The results of these squeeze tests are summarized in the attached table.

Table 8: Squeeze Test Results

Material	Trial	Dry Weight (grams)	Water Added (mls)	Water Released (mls)	Comments
FOAMS:					
Yellow foam	1	0.7273	3.3	0.0	
	2	0.7286	3.3	0.0	
	3	0.8379	3.8	0.0	
White foam	1	0.3435	3.3	0.0	
	2	0.3211	3.1	0.0	
	3	0.2870	2.8	0.0	
Hydrathane	1	0.5459	4.8	0.0	
	2	0.5873	5.1	0.0	
	3	0.5356	4.7	0.0	
FIBRES, NATURAL:					
Regular Diapers	1	0.7742	7.8	0.0	
	2	1.2261	12.4	0.0	
	3	1.2517	12.7	0.0	
Ultra Diapers	1	1.1933	33.7	1.0	max compression-31%
	2	1.3604	38.4	0.5	max compression-23%
	3	1.2229	34.5	2.5	max compression-23%
Paper Towel	1	2.9324	13.6	0.0	
	2	2.8782	13.3	0.0	
	3	2.9172	13.5	0.25	
Facial Tissue	1	2.6816	9.9	0.0	
	2	2.6689	9.8	0.0	
	3	2.6930	9.9	0.0	
FIBRES, ARTIFICIAL:					
SorbX	1	1.1200	12.3	0.5	
	2	1.0250	11.3	0.0	
	3	0.9644	10.6	0.0	
Rayon	1	2.3601	13.6	0.0	
	2	2.3018	13.3	0.0	
	3	2.5526	14.8	0.0	
GRANULARS:					
Vermiculite	1	2.3595	4.0	0.0	
	2	2.5671	4.4	0.0	
	3	2.7100	4.6	0.0	
Chemsorb	1	1.2850	6.8	0.0	max compression-23%
	2	1.2159	6.4	0.0	max compression-26%
	3	1.1666	6.1	0.0	max compression-22%

9. Viscosity Tests

The effect of the viscosity of the liquid on the absorbency of each material was determined in triplicate by using a variety of fluids ranging in viscosity from less than that of water to greater than that of water. Sucrose solutions of various composition were chosen to provide viscosities greater than that of water, since they would provide a non-volatile and non-toxic solution to work with. However, the choice of potential candidate solutions to generate viscosities lower than that of water was very limited, because water has such a low viscosity itself. All of the candidate materials were more or less volatile and toxic to some extent. The final selection consisted of methanol and acetonitrile, as well as a solution of 94% methanol/6% water by weight. The absorbency testing was therefore conducted in a fume hood. The viscosity of each test solution, as measured in the lab using a Brookfield rotating viscometer, is given below.

Sucrose,	20% by weight	1.94 centipoise
Sucrose,	30% by weight	3.18 centipoise
Sucrose,	38% by weight	5.30 centipoise
Methanol	94% by weight	0.75 centipoise
Methanol	100%	0.55 centipoise
Acetonitrile	100%	0.34 centipoise

The absorbency of the foams and fibrous sorbents was determined in the usual manner for viscosity test solutions by immersing the preweighed material for 1 minute then allowing it to drain for 20 minutes before reweighing it. The granular materials could not be tested in the Buchner funnel/burette apparatus because the sucrose solution would not flow adequately through the burette and porous glass frit. Therefore an alternative apparatus was constructed from a conical glass laboratory funnel (7.5 cm diameter at the top) and a small rubber stopper, with a 6.4 mm diameter hole drilled partially through it. A loose plug of glass wool was placed in the base of the cone and prewetted with solution, then a preweighed quantity of granular absorbent placed in the funnel. The rubber stopper was pressed onto the end of the funnel stem and the funnel filled with sufficient volume of liquid to completely immerse the granular absorbent. After one minute, the rubber stopper was removed from the glass stem and the liquid allowed to drain freely from the funnel and absorbent into a beaker. After a 20 minute drain time the material was transferred to a tared paper cup and reweighed on the laboratory balance. The test apparatus is illustrated in Appendix C on page C-11.

The results of the viscosity tests are summarized in the table on the next page and in the attached charts.

Table 9: **Viscosity Test Results**

1-Minute Absorbent Capacity - g/g
Mean & (Standard Deviation)

Material	0.35 cp	0.55 cp	0.75 cp	1.00 cp	1.94 cp	3.18 cp	5.30 cp
FOAMS:							
Yellow foam	11.2	11.2	11.3	4.04	3.36	3.38	3.46
	(2.67)	(1.06)	(1.35)	(2.39)	(0.86)	(0.60)	(2.26)
White foam	18.6	19.4	17.8	7.83	7.36	7.20	7.00
	(0.55)	(1.17)	(2.68)	(1.65)	(1.49)	(0.80)	(0.46)
Hydrathane	14.6	13.2	12.6	2.88	3.21	1.78	1.80
	(3.05)	(0.58)	(0.39)	(0.36)	(1.29)	(1.79)	(0.44)
FIBRES, NATURAL:							
Regular Diapers	12.7	12.8	12.1	20.4	20.8	22.5	24.1
	(1.62)	(0.58)	(0.96)	(0.57)	(0.53)	(1.38)	(1.37)
Ultra Diapers	7.06	9.12	8.75	40.6	20.4	25.3	18.3
	(0.94)	(1.28)	(0.42)	(1.01)	(2.44)	(2.88)	(1.87)
Paper Towel	0.66	1.32	1.71	9.56	8.16	8.66	9.51
	(0.12)	(0.24)	(0.04)	(2.01)	(0.26)	(0.76)	(0.36)
Facial Tissue	0.02	1.10	1.35	8.78	5.95	7.04	8.34
	(0.01)	(0.38)	(0.18)	(1.62)	(0.15)	(0.56)	(0.48)
FIBRES, ARTIFICIAL:							
SorbX	10.5	11.3	12.0	22.2	18.0	18.7	19.9
	(0.27)	(0.19)	(0.93)	(3.90)	(0.61)	(0.15)	(0.75)
Rayon	0.16	0.05	0.53	10.3	4.21	4.91	3.01
	(0.00)	(0.05)	(0.05)	(1.03)	(0.21)	(0.25)	(0.51)
GRANULARS:							
Vermiculite	1.95	2.13	1.84	3.44	5.02	5.02	4.18
	(0.56)	(0.57)	(0.31)	(0.12)	(0.95)	(0.42)	(0.43)
Chemsorb	7.48	5.39	8.05	9.43	12.5	15.7	14.8
	(1.09)	(1.84)	(0.95)	(1.18)	(1.15)	(2.19)	(1.08)
Fuller´s Earth	(1)	(1)	(1)	(1)	(1)	(1)	(1)

(1) - Sample of Fuller´s Earth was not received in time for inclusion in this test.

Figure 14–1: Viscosity Effects

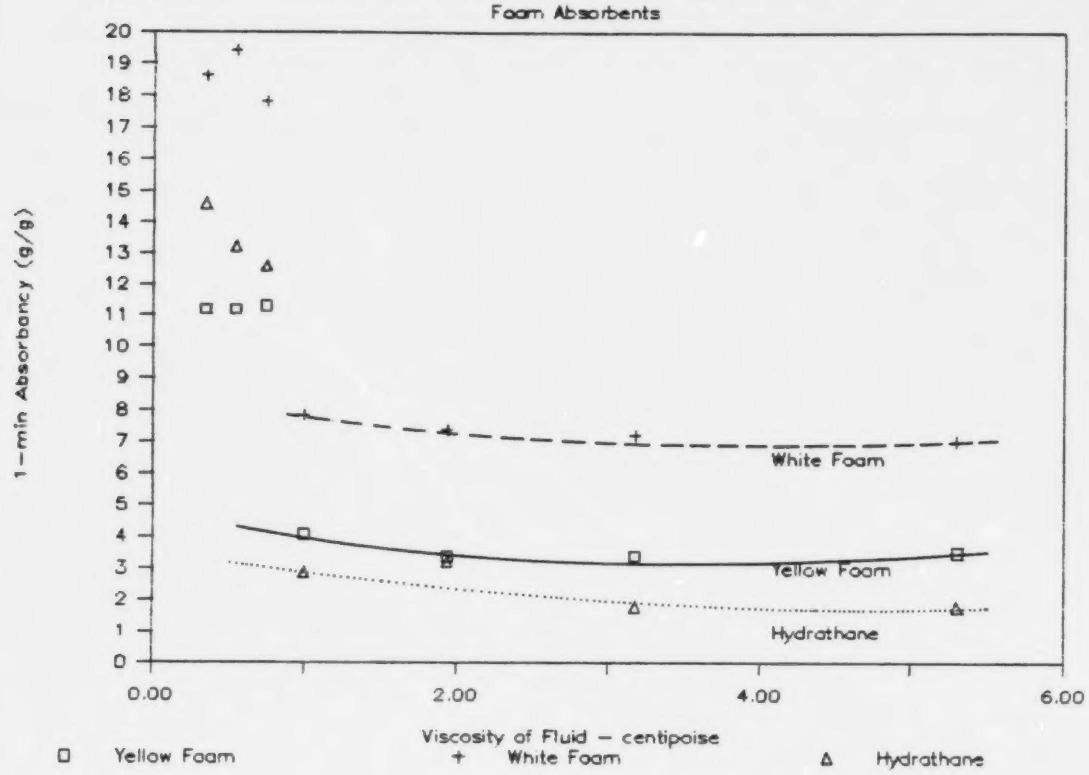


Figure 14–2: Viscosity Effects

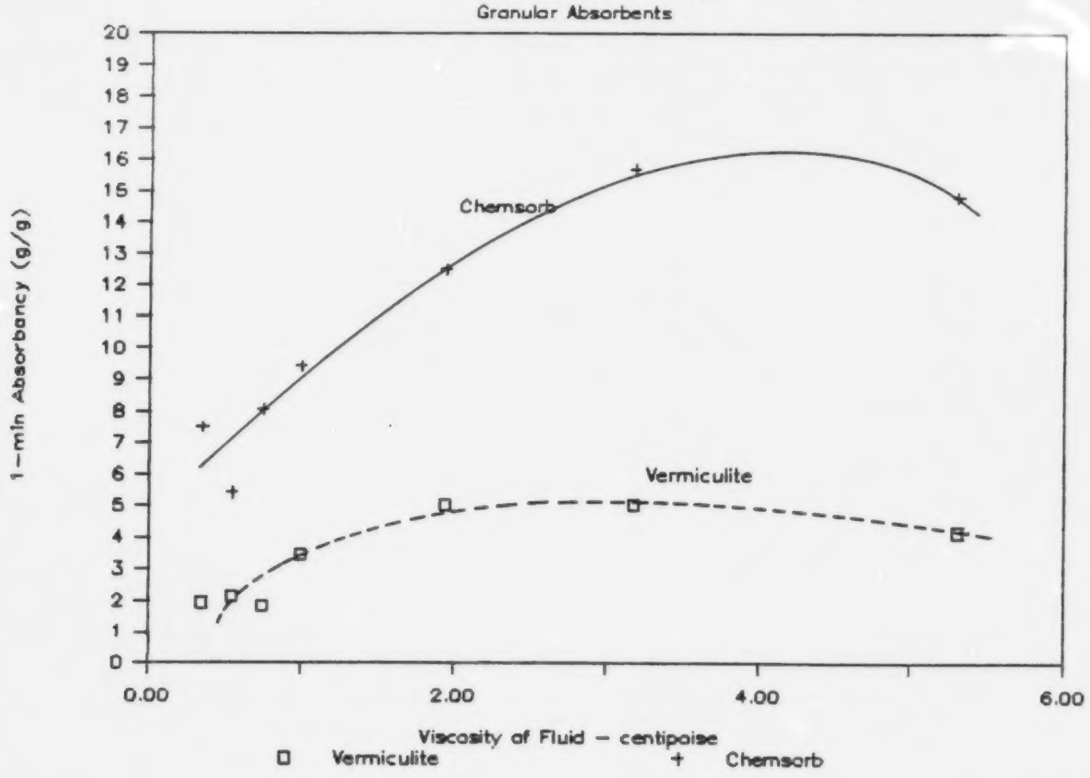


Figure 14–3: Viscosity Effects

Natural Fibre Absorbents

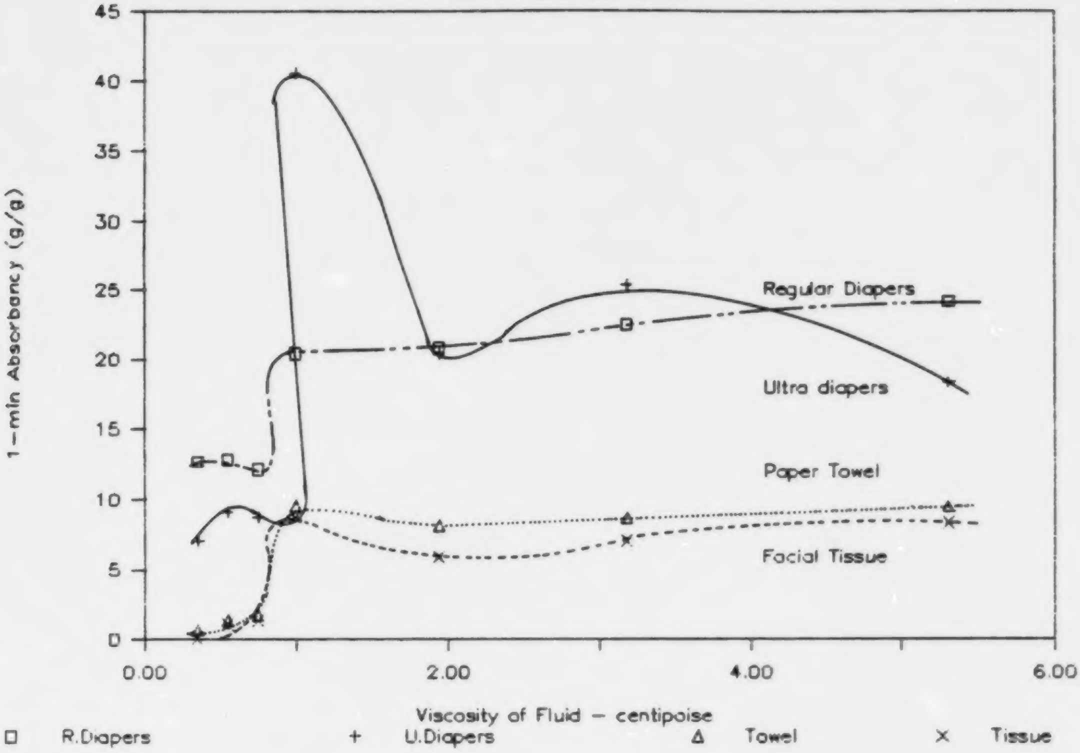
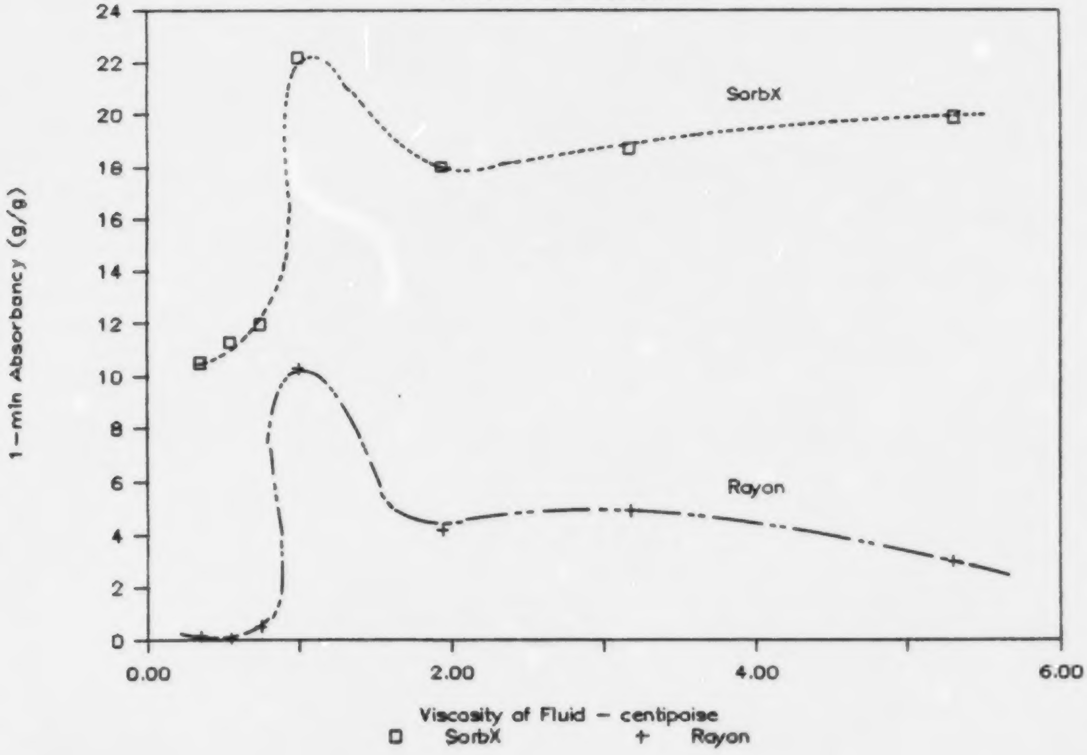


Figure 14–4: Viscosity Effects

Artificial Fibre Absorbents



10. pH Tests

The absorbency of each sorbent material was determined at a variety of levels of acidity or alkalinity in order to demonstrate the effects, if any, of pH on absorbency. A wide-range pH buffer solution was found in the literature (Geigy Scientific Tables 7th Edition) which would cover the range from pH 2.0 to 12.0. The buffer is a complex of citric acid, orthoboric acid, phosphoric acid, hydrochloric acid and sodium hydroxide in varying ratios. Solutions of nominal pH 3, 5, 6, 7, 8, 9 and 11 were prepared. The actual pH of each solution was measured to 0.01 pH units using a precalibrated Corning Model 120 digital pH meter.

The absorbency of three samples of each sorbent material was then determined by immersing the samples for 1 minute into the various pH buffer solutions and allowing them to drain for 20 minutes using either the immersion technique or the Buchner funnel/burrette technique, as described previously. A pH 7 buffer was included in the test schedule on the expectation that the absorbency of a pH 7.0 aqueous solution of various mineral salts would not be the same as that of distilled water at pH 7.0.

The results of the pH effects measurements are given in the table on the next page as well as in the attached graphs.

Table 10-1: pH Test Results

1-Minute Absorbent Capacity - g/g

Mean & (Standard Deviation)

Material	pH= 3.10	5.10	6.10	6.99	8.01	8.99	10.99
FOAMS:							
Yellow foam	1.88	3.29	2.02	3.44	6.23	3.25	3.14
	(0.59)	(0.77)	(0.46)	(0.98)	(3.31)	(0.96)	(0.57)
White foam	5.79	10.1	6.18	7.46	9.45	11.9	12.5
	(2.01)	(3.47)	(3.18)	(2.32)	(4.45)	(1.39)	(2.68)
Hydrathane	1.26	1.49	1.84	1.97	2.61	2.07	1.22
	(0.32)	(0.35)	(0.27)	(0.80)	(0.65)	(0.49)	(0.29)
FIBRES, NATURAL:							
Regular Diapers	18.9	18.6	18.2	19.8	18.3	18.6	23.4
	(0.51)	(0.38)	(0.40)	(1.07)	(1.34)	(0.72)	(0.95)
Ultra Diapers	20.8	21.1	21.0	22.0	21.2	20.2	21.5
	(0.34)	(1.25)	(1.64)	(0.50)	(1.95)	(0.73)	(3.29)
Paper Towel	6.93	6.65	7.59	6.74	6.18	7.00	6.82
	(0.56)	(0.36)	(0.73)	(0.04)	(1.95)	(0.64)	(0.16)
Facial Tissue	6.17	6.59	7.18	5.55	6.53	5.71	8.03
	(0.53)	(0.06)	(0.53)	(0.24)	(0.56)	(0.16)	(0.38)
FIBRES, ARTIFICIAL:							
SorbX	14.8	14.7	15.4	15.4	16.2	15.2	14.9
	(0.84)	(0.58)	(0.39)	(1.37)	(0.82)	(0.38)	(0.82)
Rayon	6.11	6.30	7.14	5.85	6.48	6.32	6.72
	(0.12)	(0.04)	(0.12)	(0.53)	(0.20)	(0.20)	(0.19)
GRANULARS:							
Vermiculite	4.26	3.68	5.23	4.35	3.95	3.85	4.17
	(0.28)	(0.50)	(0.39)	(0.07)	(0.94)	(0.90)	(0.07)
Chemsorb	8.70	8.58	7.32	7.56	8.83	9.91	8.02
	(0.11)	(1.75)	(0.65)	(0.91)	(1.59)	(0.81)	(0.57)
Fuller´s Earth	(1)	(1)	(1)	(1)	(1)	(1)	(1)

(1) - Samples of Fuller´s Earth were not received in time for inclusion in this test.

Table 10-2: pH Test Results

Comparison of 1-Minute Absorbent Capacity
pH 7 Test Fluids
Mean & (Standard Deviation) - g/g

Material	Distilled Water	pH 7 Buffered Sol´n	% Reduction
FOAMS:			
Yellow foam	4.04 (2.39)	3.44 (0.98)	-15%
White foam	7.83 (1.65)	7.46 (2.32)	-5%
Hydrathane	2.88 (0.36)	1.97 (0.80)	-32%
FIBRES, NATURAL:			
Regular Diapers	20.4 (0.57)	19.8 (1.07)	-3%
Ultra Diapers	40.6 (1.01)	22 (0.50)	-46%
Paper Towel	9.36 (2.01)	6.74 (0.04)	-28%
Facial Tissue	8.78 (1.62)	5.55 (0.24)	-37%
FIBRES, ARTIFICIAL:			
SorbX	22.2 (3.90)	15.4 (1.37)	-31%
Rayon	10.3 (1.03)	5.85 (0.53)	-43%
GRANULARS:			
Vermiculite	3.44 (0.12)	4.35 (0.07)	26%
Chemsorb	9.43 (1.18)	7.56 (0.91)	-20%
Fuller´s Earth	0.98 (0.10)	(1)	---

(1) - Samples of Fuller´s Earth were not received in time for inclusion in this test.

Figure 15-1: pH Effects

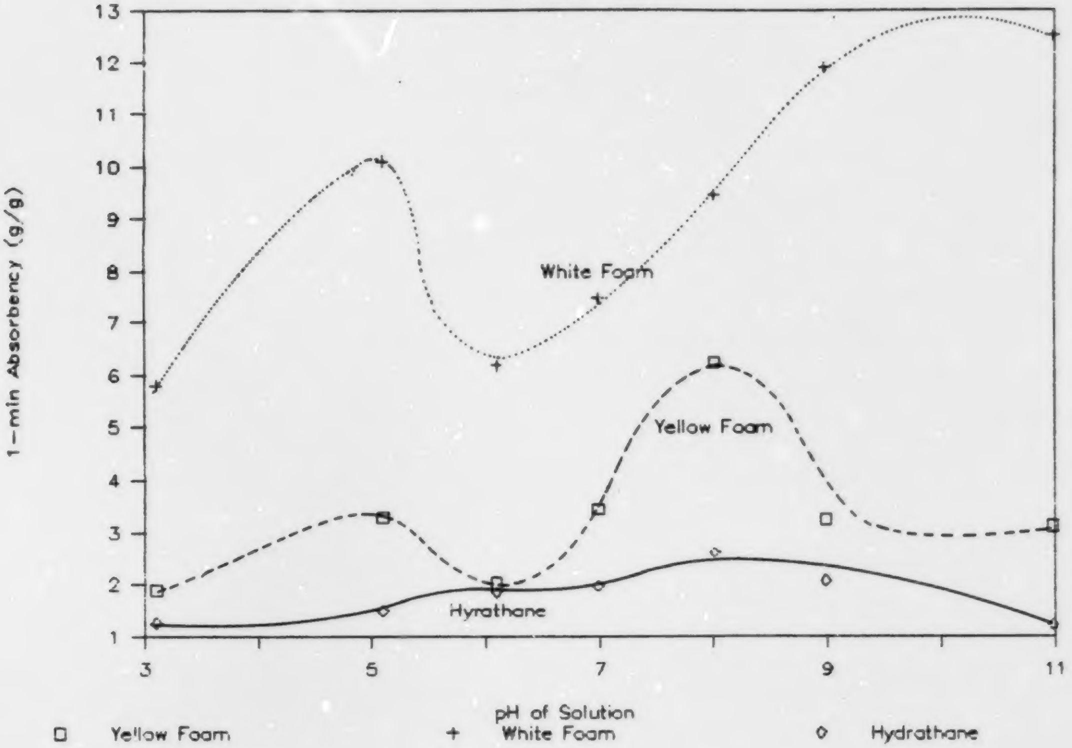

Foam Absorbants

Figure 15-2: pH Effects

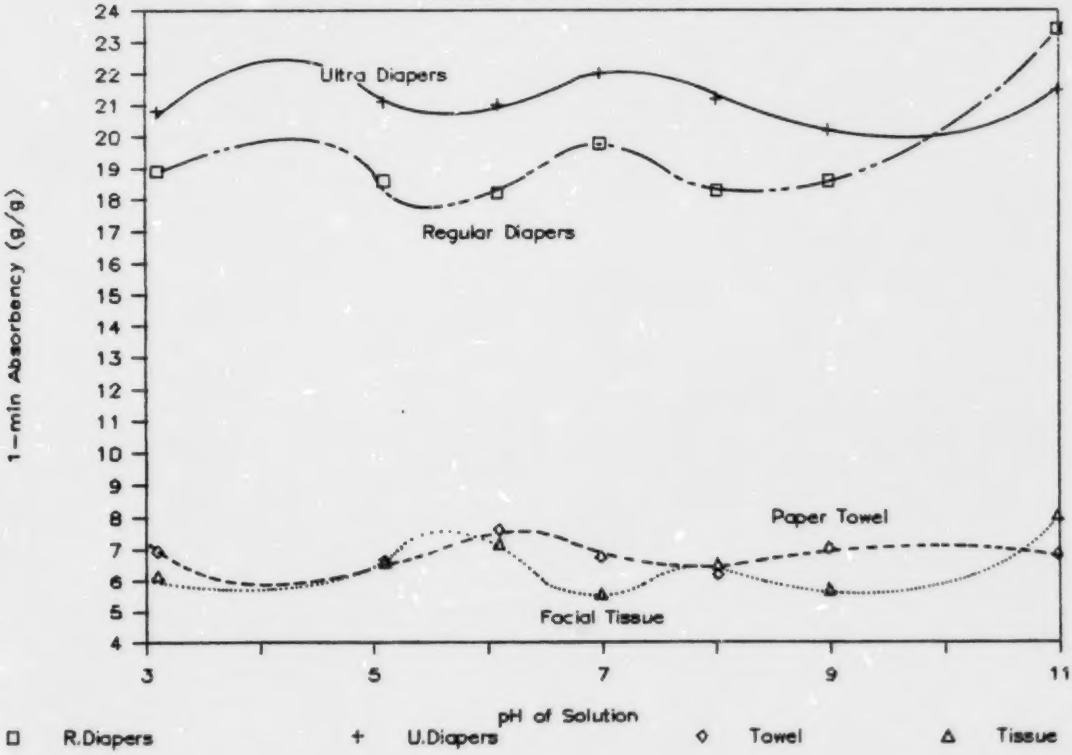

Natural Fibrous Absorbants

Figure 15-3: pH Effects

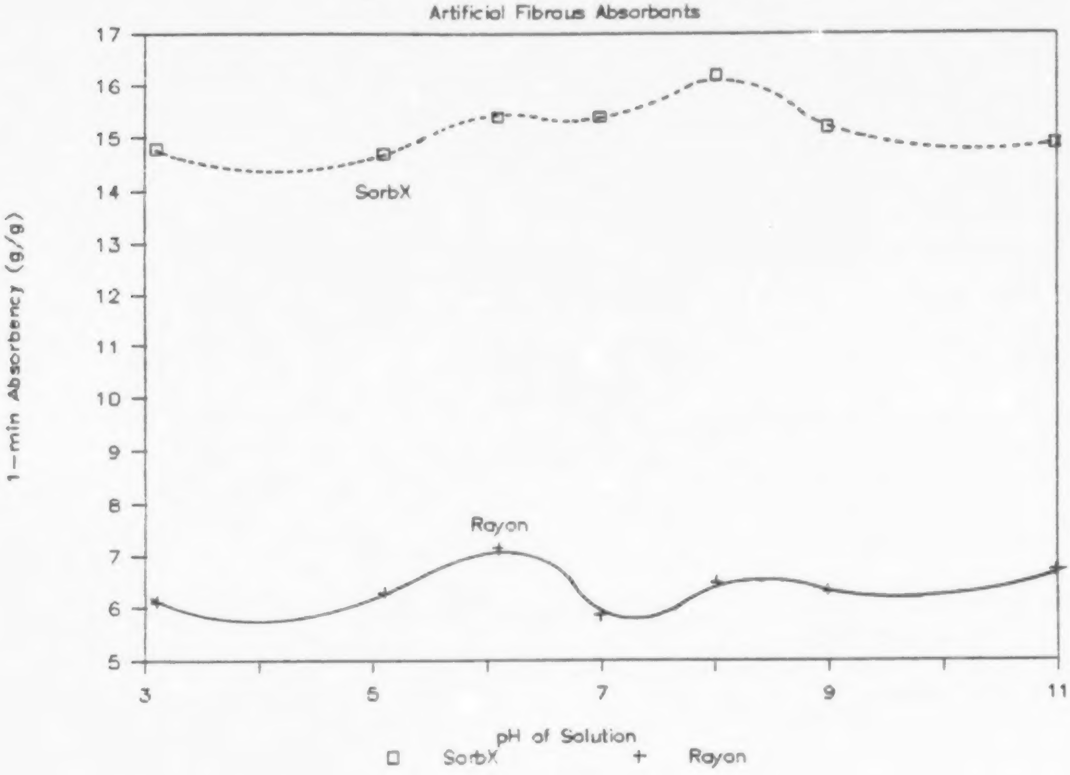
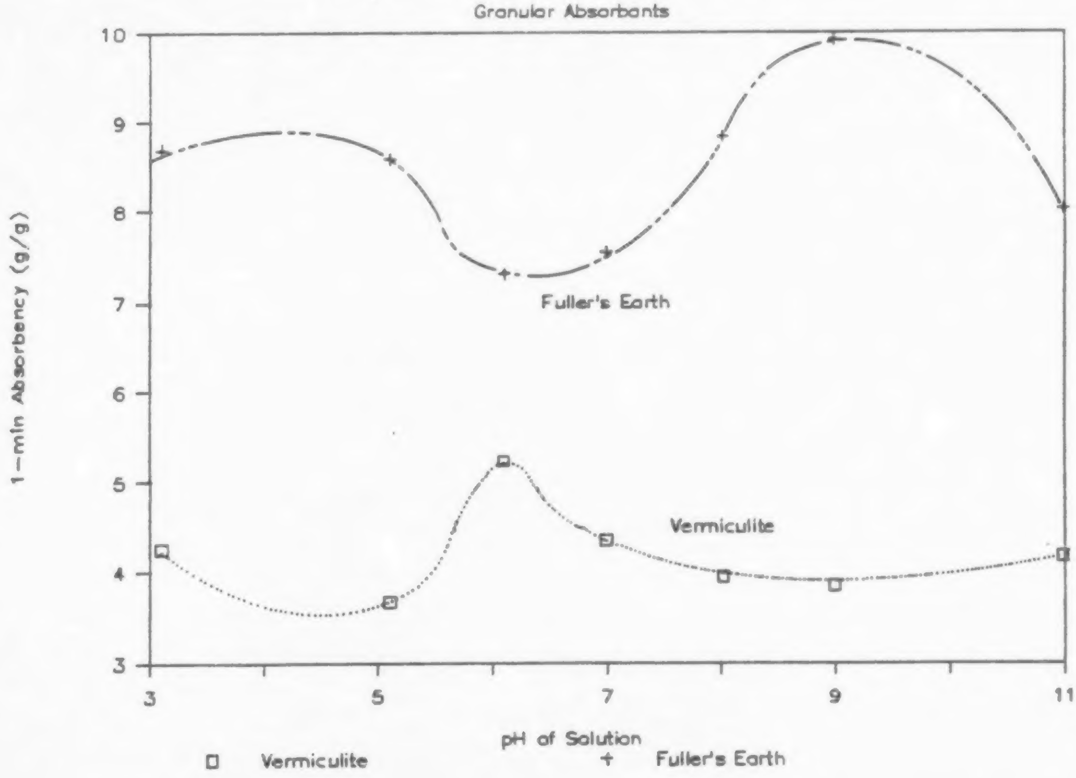


Figure 15-4: pH Effects



11. Temperature Tests

The absorbency of three test samples of each material was determined at a variety of temperatures ranging from approximately -30 degrees to +70 degrees Celcius. The actual temperatures of the tests were -28, -7, +5, +21, +30, +43 and +68 degrees. All of the tests with the exception of the lowest temperature test were conducted inside the Tenny Jr. controlled environment chamber. For the test at -28 degrees Celcius, a large chamber was constructed of 1 inch thick styrofoam sheets and was filled with several blocks of dry ice. The lid was placed on the chamber and the temperature of the chamber monitored using a mercury-in-glass thermometer pressed through the styrofoam wall.

A solution 56% (wgt) ethylene glycol in distilled water was used for the evaluation of the material's absorbency at each temperature. The freezing point of this solution is -45 degrees Celcius.

The absorbency tests were also conducted using distilled water at all temperatures above 0 degrees Celcius. Both the fluid and the solid sorbent samples were preconditioned at the desired temperature for at least 12 hours before conducting the absorbency tests. The relative humidity of the environmental chamber was also adjusted at each temperature to maintain a constant absolute humidity level of 7.75 gm H20/kg dry air, in order to condition the absorbent samples at a nearly constant level of absolute humidity while varying the air temperature.

Absorbency of the foams and fibres was tested by placing the entire immersion apparatus (beakers, wire baskets and draining stand) in the environmental chamber and conducting the testing inside the chamber. The granular materials were evaluated using the cone-shaped glass filter funnel with the rubber stopper plug, as described under the viscosity tests, since the Buchner funnel and burette apparatus was too tall to fit inside the environmental chamber and styrofoam chamber. The absorbency was determined in each case using 1 minute immersion of the absorbent material and a 20 minute drain time.

The results of the absorbency test at various temperatures are given in the tables on the next page and in the attached charts.

Table 11-1: **Temperature Test Results**

Test Fluid: Distilled Water

1-Minute Absorbent Capacity - g/g
Mean & (Standard Deviation)

Material Temp=	+5 C	+21 C	+30 C	+43 C	+68 C
FOAMS:					
Yellow foam	2.51	4.29	2.15	2.07	2.56
	(0.024)	(2.01)	(0.765)	(0.738)	(0.246)
White foam	13.4	9.9	10.7	5.44	16.1
	(5.98)	(2.18)	(8.12)	(1.89)	(4.64)
Hydrathane	3.30	3.61	7.17	3.04	6.48
	(1.16)	(0.061)	(1.52)	(0.399)	(0.751)
FIBRES, NATURAL:					
Regular Diapers	18.6	18.6	19.1	18.2	9.96
	(0.714)	(0.275)	(0.302)	(0.578)	(4.80)
Ultra Diapers	30.6	27.2	37.4	35.1	22.1
	(4.54)	(3.18)	(1.41)	(16.9)	(3.11)
Paper Towel	7.04	7.15	6.11	5.10	2.29
	(0.737)	(0.128)	(0.508)	(0.041)	(0.151)
Facial Tissue	5.55	6.56	6.17	4.54	3.40
	(0.093)	(0.438)	(0.095)	(1.15)	(0.223)
FIBRES, ARTIFICIAL:					
SorbX	15.7	14.5	14.5	14.5	11.9
	(0.533)	(0.573)	(0.374)	(0.338)	(8.07)
Rayon	6.39	6.60	5.12	4.11	2.19
	(0.172)	(0.031)	(0.283)	(0.578)	(0.254)
GRANULARS:					
Vermiculite	3.08	3.31	2.88	2.59	3.10
	(0.200)	(0.187)	(0.203)	(0.305)	(0.057)
Chemsorb	6.22	8.60	5.07	5.51	6.57
	(0.560)	(1.45)	(0.466)	(0.310)	(1.15)

Table 11-2: **Temperature Test Results**

Test Fluid: 56% Ethylene Glycol in Water

1-Minute Absorbent Capacity - g/g
Mean & (Standard Deviation)

Material Temp=	-28 C	-7 C	+5 C	+21 C	+30 C	+43 C	+68 C
FOAMS:							
Yellow foam	3.51	4.04	3.01	2.45	4.16	4.86	4.44
	(0.390)	(1.17)	(0.071)	(0.622)	(0.302)	(0.864)	(0.691)
White foam	10.2	5.74	11.7	10.2	7.57	8.73	20.4
	(6.38)	(2.84)	(6.27)	(3.39)	(3.51)	(4.27)	(4.16)
Hydrathane	4.42	2.51	2.28	1.29	2.38	2.51	5.61
	(1.27)	(1.06)	(1.49)	(0.178)	(0.738)	(0.483)	(0.728)
FIBRES, NATURAL:							
Regular Diapers	16.2	19.4	15.4	20.5	21.7	21.6	15.4
	(0.347)	(0.122)	(0.436)	(0.344)	(0.737)	(0.756)	(2.68)
Ultra Diapers	12.3	22.1	16.6	23.1	16.9	19.2	11.4
	(2.18)	(1.24)	(0.774)	(2.73)	(0.917)	(1.18)	(6.356)
Paper Towel	7.69	7.36	8.27	7.18	7.15	7.12	3.05
	(0.221)	(0.087)	(0.227)	(1.99)	(0.171)	(0.155)	(2.07)
Facial Tissue	5.57	5.36	6.67	6.94	6.81	6.30	6.88
	(0.067)	(0.503)	(0.186)	(0.399)	(0.443)	(0.125)	(0.386)
FIBRES, ARTIFICIAL:							
SorbX	16.0	15.7	17.4	15.3	15.7	16.5	16.3
	(0.662)	(0.245)	(0.437)	(0.616)	(10.2)	(0.660)	(0.500)
Rayon	1.73	1.29	0.88	1.53	1.64	0.96	1.34
	(1.04)	(0.496)	(0.188)	(0.385)	(0.791)	(0.589)	(0.962)
GRANULARS:							
Vermiculite	2.82	3.79	2.69	2.87	2.66	2.28	2.79
	(0.036)	(0.089)	(0.222)	(0.146)	(0.026)	(0.552)	(0.053)
Chemsorb	9.95	11.0	6.70	5.73	8.05	5.22	8.84
	(2.62)	(1.24)	(0.739)	(0.935)	(2.04)	(0.953)	(2.08)

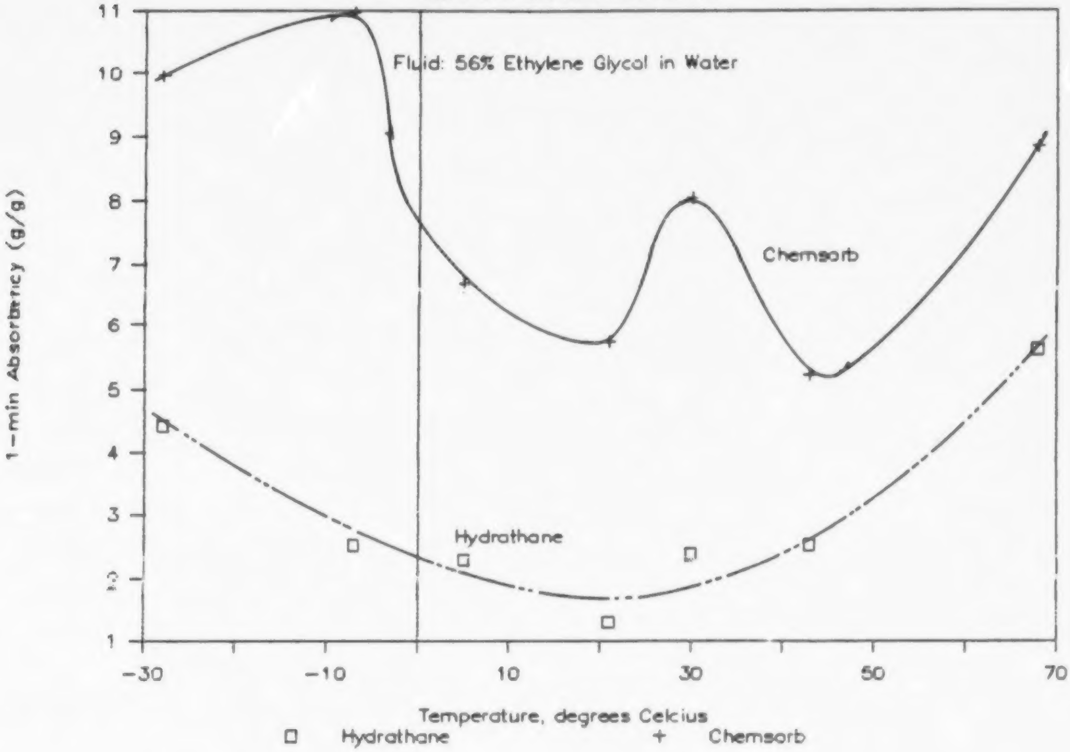


Figure 16-1: Temperature Effects

Foam and Granular Absorbants

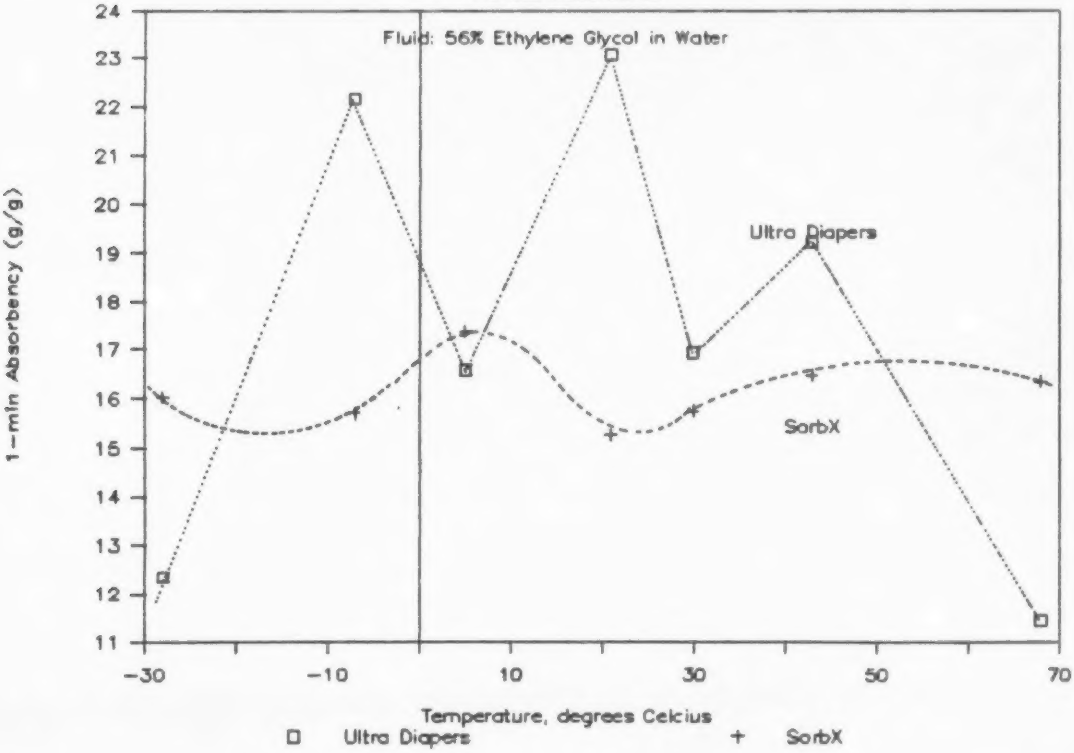


Figure 16-2: Temperature Effects

Fibrous Absorbants

12. Vibration Effects

In order to evaluate the effects of vibration upon the materials which may be compacted by vibration prior to use or in actual use, triplicate test specimens of each material were preweighed on the analytical balance to 0.1 mg, then loaded with distilled water to 50% of their absorbent capacity and subjected to an actual ground vehicle road trip of 107 kilometres using a 14 foot single axle commercial van. The absorbent materials were loaded into the 50 ml plastic centrifuge tubes with the retaining screen at the neck of the tube. Each centrifuge tube was then placed into a special holder rack made from a 120 cm length of 4.4 cm x 13.5 cm (2" x 6") lumber drilled with 2.86 cm (1-1/8 inch) diameter holes to hold each individual centrifuge tube rigidly in place. The test rack is illustrated in the attached photograph in Appendix C, page C-13.

As soon as the absorbent materials were weighed and loaded with water they were placed into the rack and the rack was nailed down to the floor boards of the truck. The truck was then driven over a preplanned route from the laboratory, west to Milton, then south to Oakville, and east to Etobicoke, and returning to the lab through Mississauga. The trip took 2 hours to complete and consisted of the following:

27 km - 22 min. - highway driving
60 km - 70 min. - secondary roads
20 km - 30 min. - city streets

The complete route followed is outlined on the attached map and consisted of the following:

-Start at Lab, Mississauga Road and Hwy 401
-South to Britannia Road
-West to First Line
-South to Lower Base Line Road
-East to Hwy 25
-South to Upper Middle Road
-East to Dorval Drive
-South to QEW
-East to Islington Avenue
-North to Dundas Street
-West to Winston Churchill Blvd
-North to Britannia Road
-East to Mississauga Road
-North to Lab

The roads travelled were all paved roads with moderate amounts of pot-holes and bumps due to broken pavement and seams across the road as this was the period of spring break-up. The portion of the trip along Islington Avenue and Dundas Street was typical stop and go driving along city streets.

A thermometer was carried in the centrifuge tube rack with the samples in the back of the truck and it recorded temperatures of 0.6 degrees C (33 degrees F) at both the start and finish of the road trip. Observation of the samples as they arrived back at the lab confirmed that none of them had frozen during the trip.

Immediately upon arrival at the lab each of the individual centrifuge tubes was examined and any evidence of fluid leakage into the bottom of the tube or compression of the absorbent material was recorded. The results of these observations are given in the table on the following page.

Table 12: Vibration Test Results

Material	Trial	Dry Weight	Water Added	Water Released
FOAMS:		(grams)	(mls)	(mls)
Yellow foam	1	0.8500	3.8	0.5
	2	0.8356	3.8	0.5
	3	0.8412	3.8	0.5
White foam	1	0.2985	2.9	0.75
	2	0.3028	2.9	1.0
	3	0.4140	4.0	1.0
Hydrathane	1	0.5727	5.0	0.0
	2	0.6892	6.0	0.0
	3	0.4916	4.3	0.0
FIBRES, NATURAL:				
Regular Diapers	1	0.5390	5.4	0.0
	2	0.5963	6.0	0.0
	3	0.5464	5.5	0.0
Ultra Diapers	1	1.1459	32.3	0.0
	2	0.8570	24.2	0.0
	3	1.0219	28.8	0.0
Paper Towel	1	2.3780	11.0	0.0
	2	2.2868	10.6	0.0
	3	2.0256	9.4	0.0
Facial Tissue	1	1.8777	6.9	0.0
	2	1.9317	7.1	0.0
	3	1.4378	5.3	0.0
FIBRES, ARTIFICIAL:				
SorbX	1	0.4222	4.6	0.0
	2	0.3967	4.4	0.0
	3	0.4140	4.6	0.0
Rayon	1	1.0924	6.3	0.0
	2	0.9692	5.6	0.25
	3	0.9191	5.3	0.0
GRANULARS:				
Vermiculite	1	2.8111	4.8	0.0
	2	3.4194	5.8	0.0
	3	2.1843	3.7	0.0
Chemsorb	1	1.2014	6.4	0.0
	2	1.2486	6.6	0.0
	3	1.1556	6.1	0.0

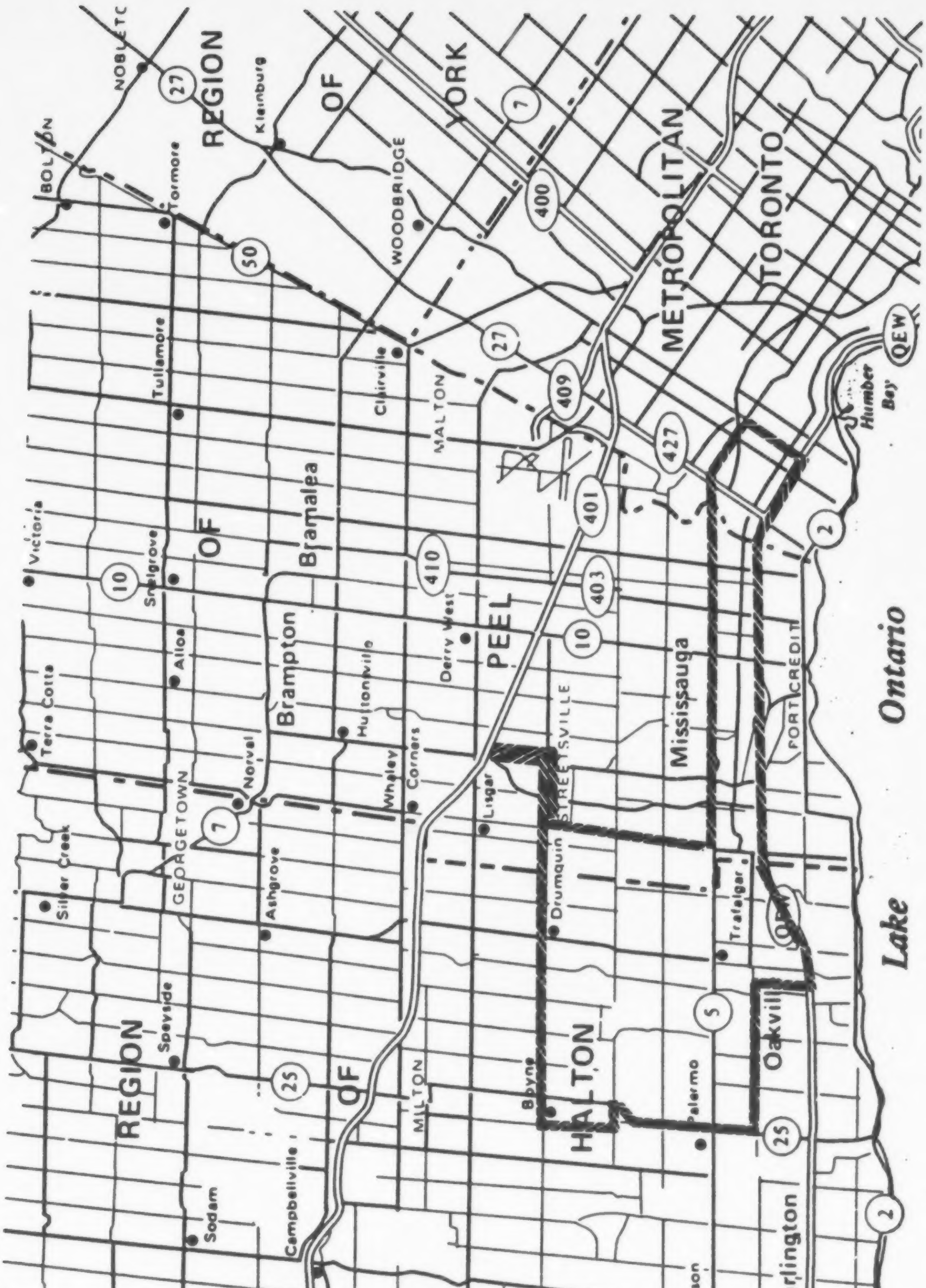


Figure 17
Vibration Road Test Route

13. Impact Tests

An impact test was conducted in order to evaluate the effect of further sudden impacts on a package where the container had already been broken and the liquid absorbed into the sorbent packaging. Suitable samples from each type of sorbent were weighed on the analytical balance then loaded into polycarbonate plastic 50 ml centrifuge tubes which contained a 7 mesh galvanized wire screen disk at the neck of each tube. For the fine grained granular materials, a pre-wetted glass fibre filter (2.5 cm diameter) was placed on top of the retaining screen before the granular material was added.

The samples were loaded with distilled water to 50 percent of their absorbent capacity based upon the sample's weight, then the centrifuge tube was capped with a tight fitting plastic cap. The height of the uncompressed sample was marked on the outside of the tube. Each tube was then placed inside a clear acrylic plastic tube, 136 cm long and 34 cm in diameter. The centrifuge tube was allowed to fall freely down the length of the tube (122 cm drop height) onto a solid concrete floor. The sample was immediately retrieved and the volume of any released water in the base of the centrifuge tube was recorded as well as any reduction in the height of the sample inside the tube.

The test was repeated in triplicate for each sample material. The results of this impact test are summarized in the table on the following page.

Table 13: Impact Test Results

Material	Trial	Dry Weight	Water Added	Water Released	Comments
FOAMS:		(grams)	(mls)	(mls)	
Yellow foam	1	0.8796	3.9	0.10	no compression
	2	1.0379	4.6	0.25	no compression
	3	1.2292	5.5	0.25	no compression
White foam	1	0.4334	4.3	0.25	no compression
	2	0.4584	4.5	0.25	no compression
	3	0.4387	4.3	0.30	no compression
Hydrathane	1	1.0479	9.2	0.25	no compression
	2	1.0330	9.1	0.10	no compression
	3	1.1737	10.3	0.25	no compression
FIBRES, NATURAL:					
Regular Diapers	1	1.6331	16.7	0.10	36% compression
	2	1.5491	15.8	0.00	40% compression
	3	1.5103	15.4	0.10	29% compression
Ultra Diapers	1	0.7771	21.9	0.00	breaks apart
	2	0.8028	22.7	0.00	breaks apart
	3	0.6818	19.2	0.00	breaks apart
Paper Towel	1	1.9595	9.2	0.00	30% compression
	2	3.0738	14.4	0.00	8% compression
	3	2.8853	13.5	0.00	16% compression
Facial Tissue	1	4.0996	15.3	0.00	7% compression
	2	3.9258	14.6	0.00	7% compression
	3	3.1124	11.6	0.00	9% compression
FIBRES, ARTIFICIAL:					
SorbX	1	1.1048	12.3	0.25	28% compression
	2	1.0383	11.5	0.25	24% compression
	3	1.1941	13.3	0.25	38% compression
Rayon	1	3.1852	18.6	0.20	20% compression
	2	3.7541	21.9	0.25	14% compression
	3	3.5430	20.9	0.25	10% compression
GRANULARS:					
Vermiculite	1	2.0370	3.5	0.00	no compression
	2	2.2992	3.9	0.00	no compression
	3	2.3190	3.9	0.00	no compression
Chemsorb	1	0.7385	3.9	0.00	no compression
	2	1.3898	7.3	0.00	no compression
	3	1.2009	6.3	0.00	no compression

E. DISCUSSION

1. Absorbency

The absorbency test results demonstrated a broad range of absorbent capacities for distilled water amongst the initial set of eighteen sorbent materials tested. Even within classes of sorbents, there were wide differences between individual types of samples. In general, the fibrous materials demonstrated higher absorbency for water than the foam materials and the granular materials demonstrated the lowest absorbency as a class. However, within each of these groups, there were exceptions to this generalization. For example, the granular amorphous silicate material known of Chemsorb demonstrated an absorbency as great or greater than that of wood chips, facial tissue, ordinary paper towels and the sample of a humidifier pad.

The diaper material containing the super absorbent polymer showed by far the highest absorbent capacity holding almost 41 grams of water per gram of material after just one minute of immersion and ultimately retaining 57 grams of water per gram of absorbent material. The diaper material without super absorbent polymer had approximately half of the absorbent capacity at one minute and approximately one-third of the ultimate capacity. The super absorbent polymer obviously increases the absorbent capacity of the cellulose pulp fluff but it also shows a slower rate of water uptake. The ultra-absorbent diaper took up an additional 41% water over its initial 1-minute capacity upon a subsequent 1-minute immersion.

The cellulose-polypropylene mat (SorbX) also showed an absorbency which was relatively high amongst the group of sorbent materials tested. It's absorption rate was also rapid, reaching full capacity upon the first 1-minute immersion. Rayon sheet was also shown to be a relatively good absorbent with a capacity of over 10 grams of water per gram of sorbent, and a rapid rate of absorption as well.

The granular mineral absorbents showed an absorbency of less than 10 grams of water per gram of absorbent, although their rate of absorption was rapid. The sample of Fuller's Earth, obtained from the Travelon Oil Company of Canada, was recommended as the most absorbent of the clay minerals. The sample of Clean Sweep was a general purpose, low cost absorbent mineral commonly used in industrial plants. Both minerals showed a low absorbent capacity for water. These clay granules are principally used in industrial settings for absorption of oils rather than water however.

The polyurethane foams showed a wide variation in absorbent capacity from 2.88 to 7.83 grams of water per gram of foam after a one minute immersion and from 5.86 to 19.7 grams per gram ultimate water absorbency. The moderate density, wide pore humidifier pad sample and the high density foam with small pores showed approximately the same capacity while the low density foam with the same small pore size showed a markedly higher capacity. This would suggest that there is not likely to be a simple correlation between absorbency and physical properties of the polyurethane foams. Interestingly, the Hydrathane foam which incorporates a super absorbent polymer directly into its matrix had the lowest one minute absorbency of the four polyurethane foams tested. However, its ultimate absorbent capacity was much higher although it took a total of six immersions of one minute each in order to reach its capacity. The super absorbent polymers, while dramatically increasing the water absorbing capacity of the products into which they are incorporated, are relatively slow in taking up that water in comparison with the supporting absorbent. The polyurethane foams, as a group, appeared to take up water relatively slowly in comparison with most of the other materials tested, requiring anywhere from one to six immersions to absorb their maximum capacity of water.

The polystyrene packing kernels, surprisingly, showed some absorbent capacity for water. This did not appear to be surface adhered water, since the weight gain did not diminish when each kernel was shaken vigorously by hand before reweighing.

The laboratory testing procedures for determining absorbency worked fairly well after some practice and experience was gained in using them. The drain times of the various materials had to be adjusted from the initially planned ten minute interval since it was found that some of the materials such as the polyurethane foams were still dripping water after ten minutes. A drain time of twenty minutes was eventually chosen for all materials as a sufficiently long period to ensure that all materials had drained sufficiently without unduly prolonging the time to complete each test.

The ultra absorbent diapers presented some unique problems in measuring their absorbency because the super absorbent polymer swells the diaper so much when wet. Samples were cut to approximately the same dimensions as the wire basket during the intial trial immersions. However, the pulp fluff disintegrated and fell through the basket into the beaker because the swelling pushed it through the screen. After some preliminary trials a sample of approximately one half the size of the basket (3.0 cm x 3.0 cm square) was found to swell to just slightly less than the dimensions of the wire basket when fully wetted. Further absorbency tests were therefore conducted with this sample size.

The reproducibility of these test procedures varied considerably with the test materials, as well as with the test procedure. In general the relative standard deviation of the three tests conducted on representative samples of each material range from 6.18% to 59.2% for direct immersion and from 2.48% to 2.80% for immersion in the wire basket as well as from 1.12% to 20.7% for the Buchner funnel/burette procedure. Better precision could undoubtedly be achieved if the tests were applied to just one type of absorbent and optimized for that material as in the testing of diapers. However, the precision is considered adequate for an overview survey of the broad field of absorbent materials.

Upon completion of the basic absorbency testing, the results were evaluated. In consultation with the project manager and the scientific authority from the Atomic Energy Control Board, it was decided to drop some of the test materials from further testing in order to test only the most absorbent materials or the most practical materials and to allow completion of the extensive testing regime within the time limits of the contract. Consequently the following materials were dropped from further testing for the reasons indicated.

Humidifier Pad - This material has a good absorbent capacity but little capacity to retain the water, which drains readily from the foam whenever it is handled or disturbed.

Polystyrene Kernels - This material showed only limited absorbent capacity and in a packaging application there would be very large void volumes between kernels which could provide an unobstructed fluid path to the outside of the container.

Absorbent Paper - This material is similar in nature and application to ordinary paper towels but has slightly less capacity to hold water. It was dropped from further testing in favour of the paper towel therefore.

Wood Chips - The samples of wood chips showed relatively low absorption capacity in comparison with all the other natural fibre materials.

Clean Sweep Clay - The two clay absorbents showed similar behaviour and it was considered necessary therfore to carry only one of the two materials through the complete series of tests.

Cellite	- The absorbency of cellite was similar to that of vermiculite while Chemsorb and Fuller's Earth had much higher and lower absorbencies respectively. Therefore cellite was dropped in favour of vermiculite, a more readily available absorbent than cellite, in order to cover the broadest range of absorbencies.

Some difficulties were experienced in obtaining the sample of Fuller's Earth from the supplier. The material was not finally obtained until well after some of the tests were completed and consequently, Fuller's Earth was not included in some of the tests.

2. Compression

Compression of each of the absorbent materials reduced the absorbent capacity as expected. When the sorbent was compressed by 20% of its original volume the absorbency was reduced by anywhere from 3.3 to 26.0% of the original uncompressed capacity. Similarily, when the materials were compressed by 60%, the absorbent capacity was reduced by 27 to 53%.

Several materials presented unique problems in this test. Fuller's Earth proved to be essentially incompressible while the vermiculite and Chemsorb could only be compressed to a limited extent. The ultra diapers could also not be compressed beyond 20%. The SorbX pad, on the other hand, collapsed by itself approximately 20% when it became wet.

It should be noted that the absorbent capacity of the granular materials tested in the uncompressed state agreed very well with the capacities determined under the absorbency test. This is to be expected since these values were determined in the same apparatus and in the same way for both tests. However, the absorbent capacity of the balance of the sorbent materials, as determined in the uncompressed state in this test, are significantly different from the values determined in the immersion test. Dr. Richard Seaman (9) pointed out that absorbent capacity values for a material were not comparable when evaluated using different techniques. The absorbent capacities for the fibrous materials were generally only 40 to 60% of those determined by immersion, while the absorbent capacity of the foams was generally greater than that determined by the immersion test.

3. Humidity

None of the materials tested showed any strong dependency of the absorption capacity upon the relative humidity at which it was preconditioned before testing. The foam materials showed inconsistent trends with the low density, white foam generally increasing in capacity at higher humidities while the higher density, yellow foam showed a maximum capacity at 50% relative humidity and the Hydrathane foam showed no significant effect at all.

The granular absorbents showed very little change in absorbent capacity with humidity as did the artificial fibre sorbents and the paper towels and facial tissue. The diaper materials showed an increased capacity at 15% relative humidity which was not observed in any other sorbent materials and could not be explained.

4. Seepage

The only materials which showed any tendency to leak or loose water after being loaded to 50% of their capacity were the foams which did not contain super absorbent polymer. All other absorbent materials showed no loss of absorbent water upon standing undisturbed for 10 minutes.

5. Wicking

The absorbent materials showed a wide variation in wicking characteristics. The polyurethane foam materials showed no wicking whatsoever. This was not surpising in the light of our experience in trying to load samples of the foam with water to 50% of their capacity. The water would sit on top of the foam and not sink into it, even after standing for ten minutes or more. Polyurethane polymer is a hydrophobic material and this obviously results in its non-wetting characteristics. Even the Hydrathane foam which was tested in this study exhibited the same characteristics. Subsequent to the completion of the laboratory testing phase of this study it was learned from the manufacturer, Scotfoam Corporation, that an improved product was under development which would incorporate both the super absorbent polymer as well as a surface-active agent into the foam in order to overcome the non-wetting characteristics of the foam. However, this newly developed material was not yet available at the time the testing was being conducted.

The fibrous materials all showed some wicking ability, with the single exception of the rayon sheet which did not wick up water above the surface of the fluid. The water uptake was relatively rapid in most cases but the height wicked was generally low, typically less than 10 cm.

The granular material Chemsorb showed high capability while the vermiculite did not. Chemsorb wicked ultimately to a height of 17 cm above the surface of the water. However, one sample of cellite which was used during a trial of the wicking apparatus showed the highest wicking height at approximately 31 cm. The extreme wicking characteristic of this flux-calcined diatomaceous earth was later confirmed when a second sample from a different supplier was tested for reasons not related to this project and was found to have almost identical absorption capacity and wicking characteristics.

6. Evaporation

The results from the evaporation test indicate that, in general, more than 80% of the added water had evaporated within the first 24 hours after the experiment was begun. Eventually all of the added water evaporated from the samples within the 8 day period. The only material to show a different evaporation pattern was the ultra diaper containing super absorbent polymer, which significantly reduced the rate of evaporation within the first 24 hours (43.5% average evaporation in 24 hours) although over the 8 day period the ultimate evaporation was similar. The incorporation of super absorbent polymer into the Hydrathane polyurethane foam did not significantly reduce water evaporation from this material, perhaps because there appeared to be less SAP in the Hydrathane foam than in the ultra diapers.

7. Squeeze Tests

The only material to show a consistent loss of water upon being compressed in the wet state (loaded to 50% of its capacity) was the ultra absorbent diaper material which was being compressed to the maximum possible degree. This was a somewhat unexpected result in as much as the super absorbent polymers are reported to be much more effective than ordinary pulp fluff at retaining their absorbed water under compression. However, even at its maximum compression it was only losing between 1 and 7% of its absorbed water volume.

For both the paper towel and the SorbX samples, one of the three samples showed a loss of 0.5ml of water or less while the other two samples in each set showed no detectable water loss.

The results suggest that moderate compression of absorbent materials after an accident would not generally release fluid from the absorbent.

8. Viscosity Tests

The results of the viscosity tests show no obvious or clear-cut trends in absorbency with change in viscosity of the fluid. For most of the materials tested there is a large discrepancy between the capacity measured at viscosities less than that of water and greater than that of water. This is believed to be due in large part to the nature of the fluids used rather than the actual difference in viscosity. In order to obtain viscosities less than 1 centipoise it was necessary to use the organic solvents methanol and acetonitrile. It happens that polyurethane foams have a high absorbent capacity for these organic solvents in comparison to water, while most of the other materials appear to have a lower absorbent capacity for such organic solvents.

The SorbX and rayon samples as well as the ultra diaper samples showed a significant drop in absorbent capacity from that of pure water when the fluid was switched to either sucrose solutions or organic solvents. The other materials did not demonstrate a drastic reduction in absorbent capacity when varying concentrations of sucrose were added to the distilled water.

With the sucrose solutions no consistent trends could be identified with some materials showing slightly increased capacity at higher viscosities and others showing slightly reduced capacity at higher viscosity. There were no drastic changes in absorbency in either case suggesting that the effect of viscosity is generally likely to be small.

9. pH Tests

As with the viscosity tests, the results of the pH tests suggested no strong dependence of absorbent capacity upon the pH of the solution over the range from pH 3 to 11. Most materials maintained a fairly consistent absorbent capacity across the full range of pH values tested. Hydrathane foam showed the most consistent effect with a maximum absorbence at pH8 which progressively dropped off to less than 50% of that value at both pH 3 and pH 11.

The presence of the ionic species in the pH 7 buffer solution reduced the absorbent capacity of all materials except vermiculite. The unmodified foams and the regular diapers were relatively unaffected by the presence of salts in the distilled water solution but the ultra absorbent diapers, facial tissue and rayon sheet showed reductions of more than 35% in capacity. Strangely the vermiculite showed an increase of 26% in capacity for the pH 7 buffer.

A simple experiment was also conducted to evaluate the stability of the foams and fibres in both strong acid and strong alkali solutions. Solutions of 50% sulphuric acid and 10 N sodium hydroxide were prepared in individual glass beakers and samples of each material were placed within the solutions for one hour. The type of acid and alkali as well as the solution strength were chosen arbitrarily. The observed reactions are given below.

Material	50% Sulphuric Acid	10% Sodium Hydroxide
Yellow Foam	Turned dark pink & very flimsy	Remained intact, no visible change
White Foam	Turned very flimsy, no colour change	Remained intact, no visible change
Blue Foam	Turned mustard yellow, very flimsy	Remained intact, no visible change
Ultra Diapers	Turned mustard brown in seconds, fluff charred in 1 hr, dry weave and moisture barrier remained intact	Pulp fluff dispersed, and moisture barrier remained intact
Reg. Diapers	Disintegrated within seconds, charred in 1 hour, moisture barrier intact	Dispersed, dry weave and moisture barrier intact
Paper Towels	Disintegrated within seconds, charred after 1 hour	Remained intact, no visible change
Facial Tissue	Disintegrated within seconds, charred after 1 hour	Remained intact, no visible change
SorbX	Turned mustard brown in seconds, charred after 1 hour	Remained intact, no visible change
Rayon	Disintegrated and charred after 1 hour	Remained intact, no visible change.

10. Temperature

The results of the tests to measure absorbent capacity of the materials for distilled water at different temperatures were rather inconclusive. There was a great deal of scatter in the data generated which made the interpretation of any trends difficult, particularly for the foam materials. The fibrous materials generally indicated some reduction of absorbent capacity with increasing temperature while the granular materials showed generally little significant effect.

When the fluid was switched to 56% ethylene glycol in water, and the low temperature range extended to -28 C, the data were no clearer to interpret. The foam materials generally appeared to indicate a minimum capacity at about +21 C, as illustrated by the Hydrathane results in Figure 16-1. The fibrous materials generally tended to show little effect of temperature on absorbent capacity for ethylene glycol/water as illustrated by the data for SorbX in Figure 16-1. However, the data for the ultra diaper were very divergent and showed significant differences at various temperatures but no consistent trend emerged (Figure 16-1). The granular materials also showed no clear-cut trend in capacity with temperature. The substitution of an ethylene glycol/water mixture for pure distilled water had no consistent effect upon the absorbency of most materials at +21 C except for the rayon which showed a significantly lower capacity for the ethylene glycol/water mixture than for pure water.

11. Vibration Road Test

The road test subjected the samples to an actual 100 km trip in the back of commercial van which has a relatively short wheelbase and therefore a somewhat choppy ride. As with the seepage test, the only materials to show consistent loss of fluid were the yellow and white polyurethane foam materials. One of the three rayon samples lost 0.25 ml of water or 4% of the water loaded into the sample, while the other two rayon samples did not loose any liquid.

None of the materials, including the granular materials, showed any compaction or reduction in volume over the two hour road trip.

12. Impact Tests

The impact test results differed from the results of the road test. More of the materials demonstrated some loss of liquid upon impact and the same materials also showed measurable compaction. All three foam materials showed consistent loss of water but no compression on impact. The fibrous materials all showed some compaction and the super absorbent diapers broke apart upon impact. The regular diapers as well as the SorbX and rayon materials also showed some water loss. The granular materials showed neither compaction nor water loss upon impact after a 122 cm (4 ft) drop onto a solid concrete floor.

F. CONCLUSIONS

1. Theory and Principles

The parameters which govern the effectiveness of different types of absorbent materials have not been studied in any comprehensive way in the literature to date. Some of the basic principles have been defined and theoretical models developed for the rate of absorbency for pads of cellulose pulp fluff but no model has yet been developed which can successfully predict the absorbent capacity of various materials. The Lucas equation for vertical wicking and the Lucas-Washburn equation for horizontal wicking in capillaries have been given in this report along with the equation given by Dr. Dale Wilson for wicking in capillary pores based on an analysis of Aberson's work. These are the three principle theoretical models relating to capillary absorbency.

The absorbent capacity of potential absorbents is influenced principally by the contact angle made between the liquid and the absorbent material as well as the diameter or size of the pores and the total void volume in fibrous or porous cellular materials. Highly wetting pulps have a small wetting angle and a rapid rate of absorption. However, all other factors remaining equal, high rates of absorption were generally associated with low liquid-holding capacity. The absorbent capacity is directly related to the void volume of the fibrous or cellular material.

Fibrous materials, specifically cellulose pulp fluff, generally have the highest absorption capacities reported in the literature while granular materials generally have a much lower absorption capacity when measured in terms of grams of water absorbed per gram of material. References to absorbent capacity of open cellular foam materials could not be found in the literature for water absorption but were found in relation to the absorption capacity for crude oil on water. Information on the performance and capacity of special absorbents known as super absorbent polymers was also obtained from the literature indicating that they have a very high ultimate capacity for water absorption of 30 to 40 grams per gram of material.

2. Test Methods Reported from the Literature

Currently, most methods used to test the absorbency of materials are specifically focused on the evaluation of cellulose pulp fluff as it applies to it's performance in diapers , etc. There are no industry-wide or consensus testing methods with the exception of ASTM method D-1117, "Standard Methods of Testing Non-Woven Fabrics", which incorporates a section on the determination of Absorbency Time and Absorptive Capacity. This ASTM method is frequently used to evaluate sheet, pad and bulk type absorbents. However, D-1117 is not practical for loose granular materials typical of some packaging uses. Other specific test procedures developed by individual firms for use in their own product evaluation programs vary widely and do not produce consistent determinations of absorbent capacity for common materials. None of the current tests reported in the literature provides a universal test procedure which can be applied to all types of materials such as fibre pads, foam blocks and loose granular materials. Most current test methods also use 0.9% saline solution or synthetic urine solutions of somewhat variable composition in preference to water in order to more nearly simulate final end use in the diaper industry. The current test methods do not provide an adequate test procedure in themselves, but do provide a basis for generation of a universal test procedure applicable to a variety of test materials in both fibrous and granular form.

3. Current Test Methods

The test methods developed as part of this project and detailed in this report can be used to evaluate the absorbent capacity of both granular materials and fibrous or foam materials, and should be able to be reproduced in most laboratories having access to basic chemical laboratory equipment. However, the two test methods reported here for the determination of 1-minute absorption capacity do not produce the same value for absorbent capacity when testing samples of the same material. It will therefore be necessary to identify not only the absorbent capacity of the material but also which test procedure was used to determine that value in order to evaluate the significance of the value reported. The magnitude of the difference in absorbent capacity as determined for the same material by the two different methods can be seen by comparing the results of the 1-minute absorbency tests for Table 2 with the 1-minute absorbency in the uncompressed state during the compression tests as reported in Table 3. The foam and fibrous materials were tested by the total immersion method in Table 2 and by the Buchner funnel/burrette method in Table 3, while the granular materials were tested by the burrette method in both Tables 2 and 3. This comparison indicates an increase in absorbency by the burrette method for the foams but a decrease in the absorbency by the burrette method for the fibrous materials, regardless of whether the fibrous materials swelled significantly (ultra diapers) or not (paper towel and rayon). The absorbency for the granular materials, on the other hand, was only 5 to 7% less, when determined by the burrette method a second time for the uncompressed state in the compression tests. It is therefore evident that the absolute value of absorbent capacity will depend not only upon the material itself but also upon the method which is used to determine it.

In general, satisfactory precision was obtained in repeat determinations of each of the tests conducted during this project. All tests were carried out in triplicate for each material and the variation amongst a set of test data for the three trials was typically 20% relative standard deviation or less. The standard deviation of the data sets for 1-minute absorbency and ultimate absorbency are given in Table 2, indicating the precision with which the absorbency of each material could be determined. There did not appear to be a major difference in the precision obtained with the immersion method as compared with the burrette method. The test methods are simple and straightforward enough that they should be able to be set up and repeated successfully by other laboratories, although this was not evaluated as part of this project.

Several months after completion of the testing phase of this project a sample of Dicalite, a flux-calcined diatomaceous earth similar to Cellite, was obtained and the apparatus set up again to determine the absorbent capacity and wicking performance of this material. Both the absorbent capacity (1 minute absorbency: 2.06 g/g for Cellite and 2.06 g/g for Dicalite) as well as the wicking performance (1 minute height: 6 cm for Cellite and 5.5 cm for Dicalite, ultimate wicking height 30.9 cm for Cellite and 29.0 cm for Dicalite) compared well between the two tests conducted by the same lab but months apart in time, suggesting that the test procedures are sufficiently rugged that they may be set up at different times yet yield equivalent results.

The choice of one minute as a time interval for determination of the absorbency appears to be a good choice since many of the sorbent materials are at or nearly at their ultimate absorbent capacity within one minute of contact with the fluid. Some materials, however, such as the foams and the ultra absorbent diapers containing the super absorbent polymer are much slower to absorb fluids and their ultimate absorbency is not adequately reflected by the one minute absorbency value. In evaluating the suitability of candidate absorbents for transportation of radioactive liquid materials, the one minute absorbency value should be considered as a prime parameter and the ultimate absorbency as a secondary parameter because, in the event of a spill, any fluid not absorbed within one minute may have time to flow through channels in the packing and reach the outer surface of the package thus escaping absorption and immobilization.

For most of the materials tested under this project, absorbent capacity information was not available or published by the manufacturer. However, for the Hydrathane foam, SorbX fibre, Chemsorb granules and the Fuller's Earth granules, information was available from the manufacturer or supplier concerning the absorbency of the product although no information was given on just how that absorbency was determined in some cases. The following table compares the ultimate absorbency for distilled water determined from this project with the water absorbency reported by the manufacturer or supplier for each of these materials.

Absorbency - g water/g material

Material	Manufacturer's Literature	Experimentally Determined
Hydrathane foam	36.8	17.6
SorbX fibres	15	22.2
Chemsorb granules	8.4	9.57
Fuller's Earth	1.16-1.25	0.98

These results show some measure of agreement for most materials except the Hydrathane foam which did not approach the manufacturer's value for absorbency.

The granular materials, as a class, have relatively low absorbent capacity on a weight per weight basis, compared to the fibrous and foam materials. However, due to their greater bulk density, their absorbency on a weight per volume basis compares more favourably with that of the fibrous and foam materials. For example, it would require approximately 59 cm3 of vermiculite or 22 cm3 of Cellite to absorb 10 ml of water and not exceed 50% saturation, while it would require 940 cm3 of polystyrene packing kernels, 150 cm3 of white foam or 7.5 cm3 of regular diaper material to accomplish the same task. Thus, the volume of the final package required can be significantly influenced by the choice of absorbent packaging material chosen.

The incorporation of super absorbent polymers within the absorbent material matrix can very significantly increase the capacity of that material to absorb water. However, the uptake of water by these super absorbent polymers is relatively slow, requiring a period of several minutes at least to reach full capacity. In the context of an absorbent for a spill therefore they would be less effective than a material with a lower total absorbency but much more rapid uptake or wicking of the liquid. Also the super absorbent polymers swell drastically upon wetting and would therefore increase the internal pressure within the package in the event of a leak. This could potentially cause rupture of the package or crushing of unbroken containers in the same shipment. Super absorbent polymers also show a much greater reduction in capacity for solutions in water and for non-aqueous fluids than do most other sorbent materials. Therefore they have some disadvantages in the context of absorbent materials for radioactive materials packaging. Judicious use of small amounts of super absorbent polymers incorporated into other sorbent materials may, however, overcome most of these drawbacks.

Such parameters as relative humidity of the environment in which the absorbent is stored, as well as the temperature, pH and viscosity of the test fluid appear to have little significant influence upon the absorbent capacity of the material. Standing, squeezing and vibration also had little effect upon the drainage or loss of water from a sample of absorbent material previously loaded with water to 50% of it's capacity.

Determination of the absorbent capacity of materials under various states of compression generally indicated reductions in capacity commensurate with the degree of compression. These tests were therefore not considered necessary for future evaluation of absorbent materials.

The wicking performance of most materials was generally very rapid, with the time to reach the final wicking height being generally less than 5 minutes. Therefore, in order to follow the wicking performance more precisely, it is recommended that the wicking height be read at more frequent time intervals such as 10 or 15 seconds rather than the 30 second intervals used in this project.

The time recorded to reach final wicking height shows considerable variation because it is determined by visually estimating the point at which the liquid level does not increase by 1 mm or more in a period of 30 seconds. Since the wicking height increases with the square root of time the process becomes rather slow as the fluid nears it final height and since observations were made at only 30 second intervals, it was often found that differences of a minute or more were observed between replicate samples of the same material. Using a shorter interval for repeat observations would perhaps reduce this variability somewhat but would not eliminate it since the value is based upon a judgement as to just when the liquid height in each column ceases to increase. The time to final wicking height is therefore not a particularly precise measurement.

All of the sorbent materials rapidly lost absorbed water through evaporation when exposed to the air at 21 C and 50% relative humidity. Water evaporation was so rapid that most samples lost 80-90% of their absorbed water within 24 hours. If evaporation is to be evaluated effectively therefore it must be monitored on a time interval much shorter than that used in this study. However, for regulatory purposes it may be sufficient to know that most absorbents loose the majority of their absorbed water within 24 to 48 hours and more precise data may not be required.

The results of the series of temperature tests was inconclusive due to wide variability in the data obtained. The experiment should be repeated in order to obtain more consistent results before finally concluding whether the test is valuable or not.

The vibration road test is obviously not a scientifically reproducible test, particularly when tests are conducted by different laboratories in different parts of the country. The results from the impact test would suggest that it is an even more severe test of the absorbent's ability to retain water under conditions of sudden jarring and it is therefore recommended that the impact test be considered in preference to the vibration road trip test.

G. RECOMMENDATIONS

(1) Based upon the experience gained in the performance of each of the tests in this project and a review of the data obtained from a wide variety of different types of absorbent materials, the following battery of tests is recommended as a satisfactory screening tool for candidate sorbent materials.

(i) 1-Minute absorbency
(total immersion or burrette method)

(ii) Ultimate absorbent capacity

(iii) Wicking performance
(10-15 sec observations)

(iv) Impact test

(v) Chemical compatability test

(vi) 24-48 hr Evaporation test
(if considered necessary)

(2) The effects of temperature on absorbent capacity should be restudied to determine if there is any consistent and significant effect which this project failed to identify.

(3) The rate of evaporation should be determined at intervals of 1 to 3 hours over the first 24 to 48 hours for absorbent materials if it is considered important to identify rates of evaporation precisely.

(4) A more detailed study of a wider variety of candidate absorbent materials should be conducted using the above testing regimen. Candidate materials could be most appropriately selected by reviewing current packaging and shipping practices with regard to liquid radioactive materials.

(5) The battery of absorbency test methods should be repeated on a few select materials by several test laboratories in order to establish the operability and ruggedness of each method and the reliability of the test data.

D-1117-80 CAPACITY & RATE TEST

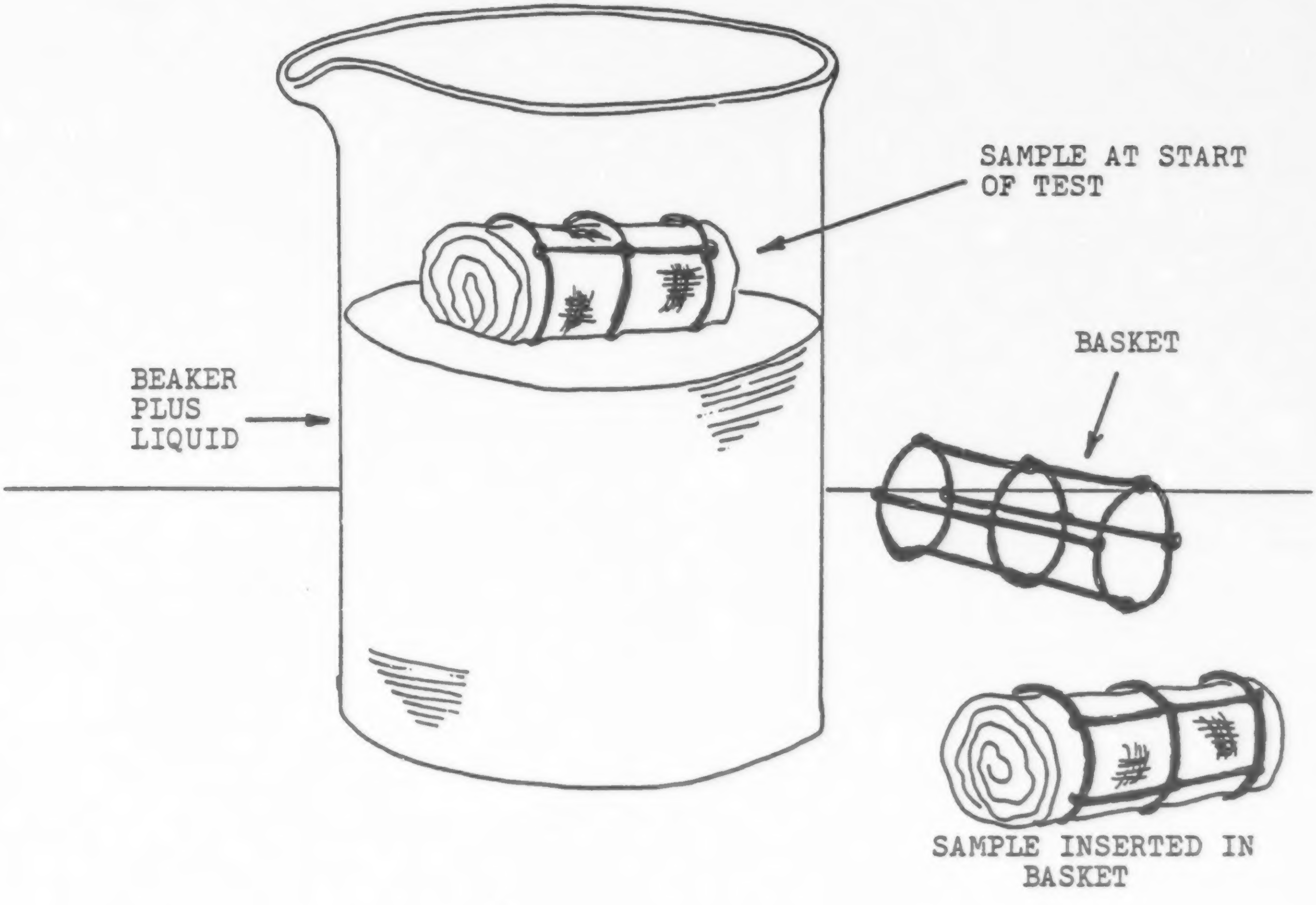


Figure 6

D-1117 TEST (LARGE SAMPLE)

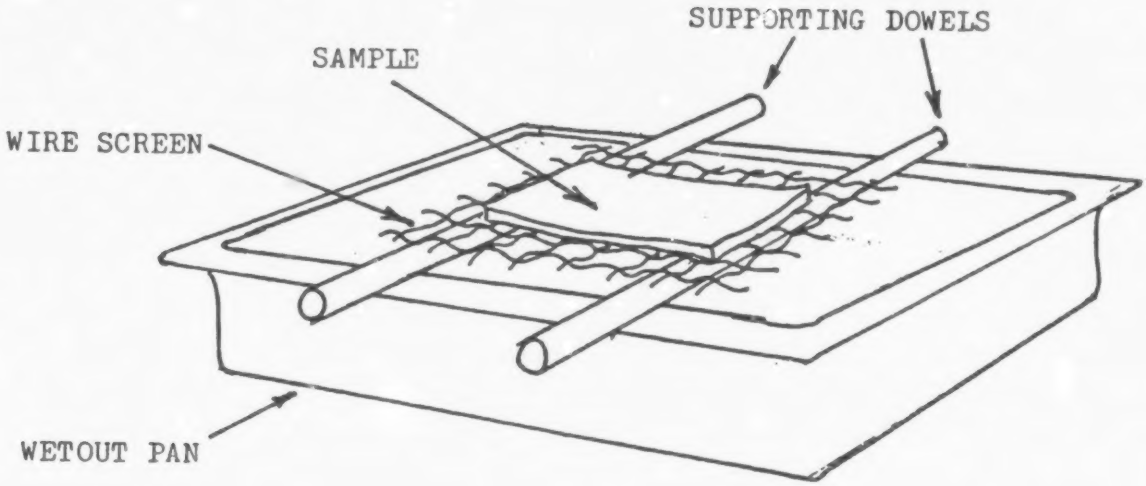


Figure 7

CAPILLARY ABSORBENCY TEST

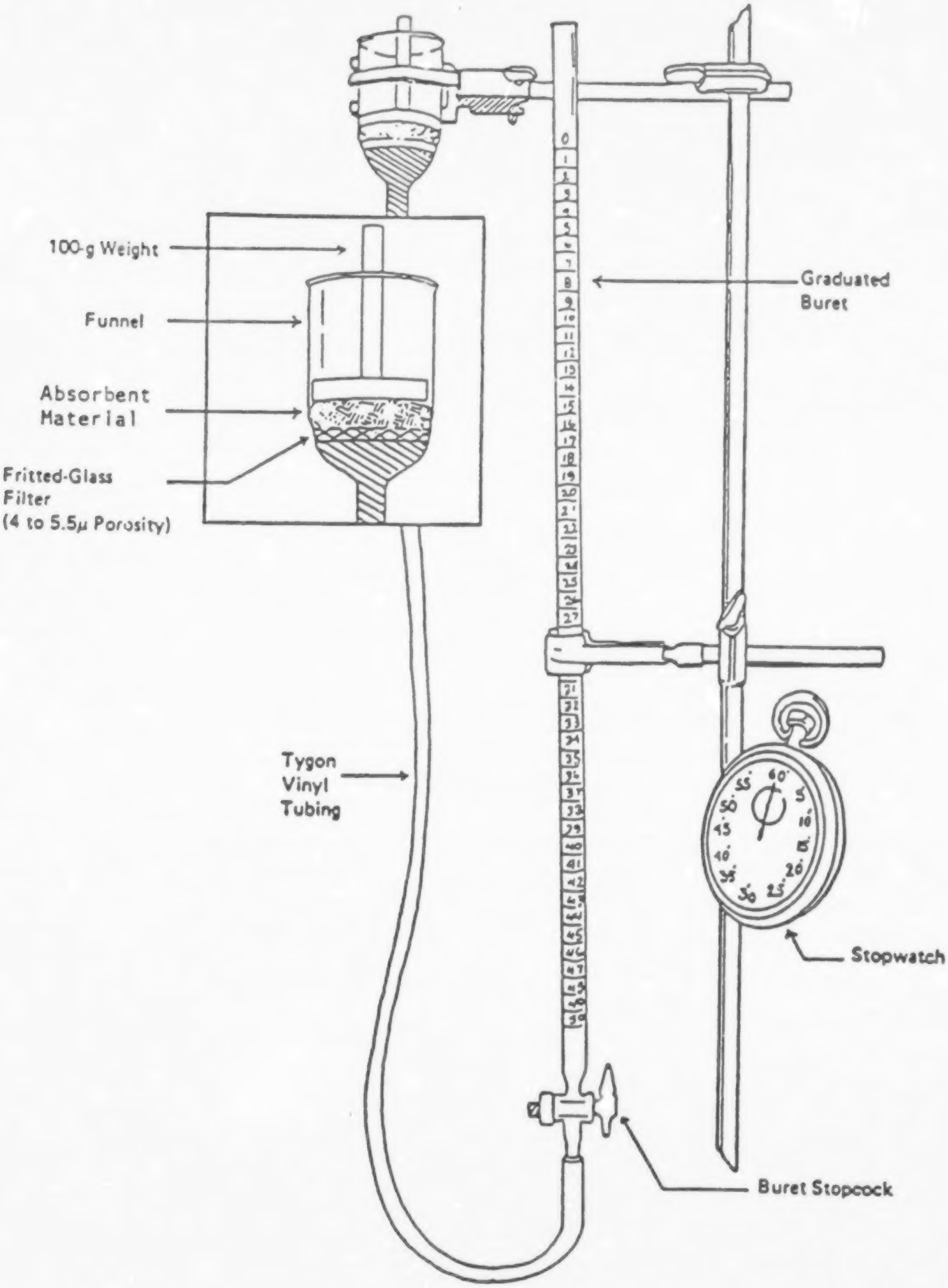


Figure 8

Demand Absorbency Test (DAT) Apparatus

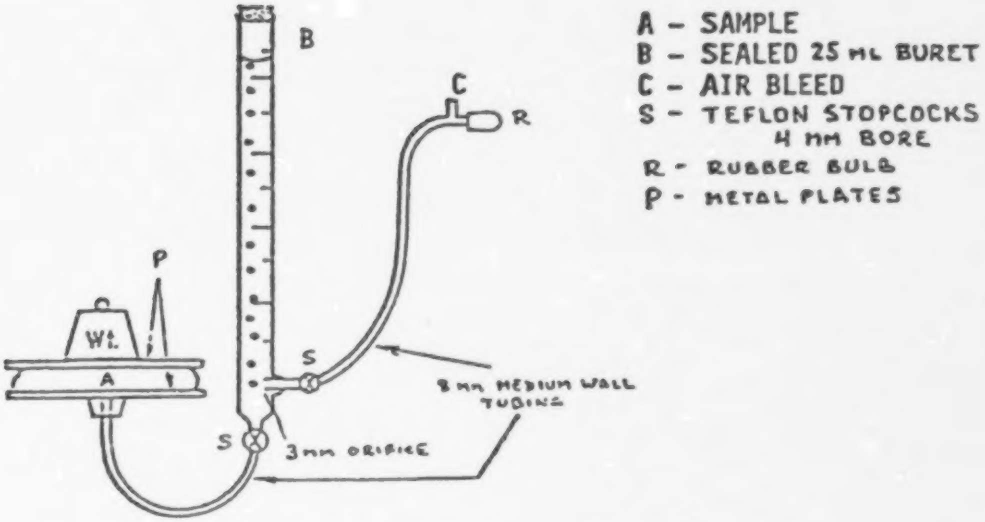
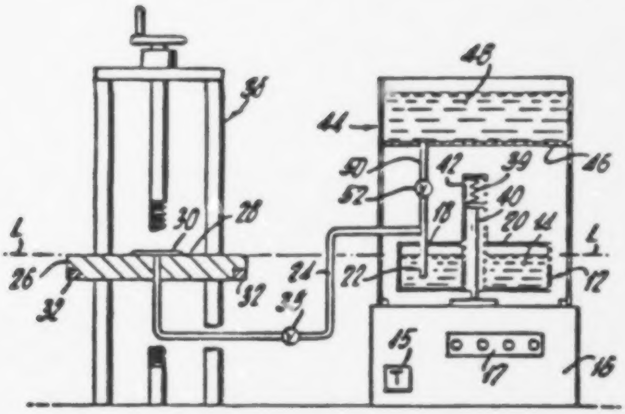


Figure 9-1



ELECTRONIC
DEMAND WETTABILITY
INSTRUMENT

Figure 9-2

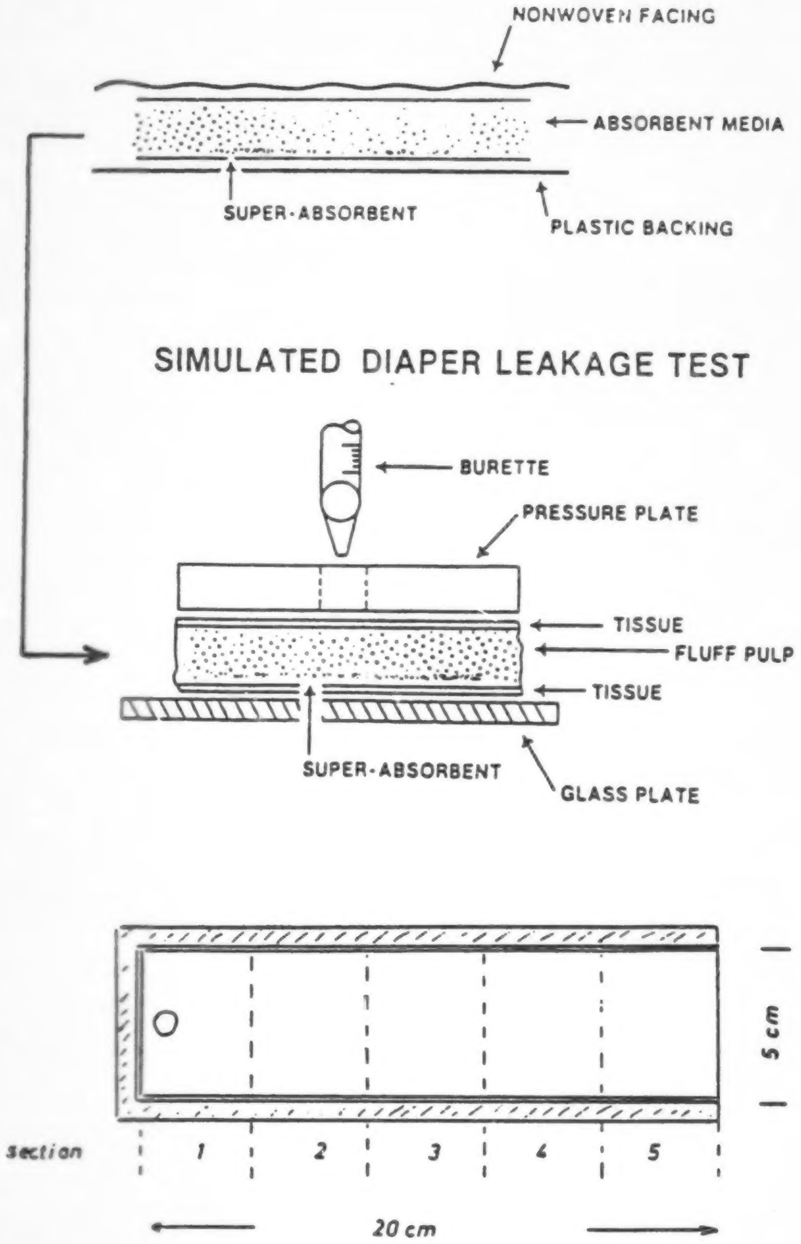

NONWOVEN FACING
ABSORBENT MEDIA
SUPER-ABSORBENT
PLASTIC BACKING
SIMULATED DIAPER LEAKAGE TEST
BURETTE
PRESSURE PLATE
TISSUE
FLUFF PULP
TISSUE
SUPER-ABSORBENT
GLASS PLATE
5 cm
section
1
2
3
4
5
20 cm

Figure 10

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Appendix A

Selection Criteria and Laboratory Evaluation of Oil Spill Sorbents

Type of Sorbent Tested	Physical Properties	Performance	Comments
Wood fibre product Marketed as animal bedding - Bedex	Bulk Density 27.2 Kg/m3	Water absorption ratio 12.5:1; up to 90% of the product sank during 48 hr immersion test with Bunker C fuel	Marketed for animal bedding Oil absorbency testing limited to laboratory
Conwed-Surface treated cellulose. Modified organic	Bulk Density 51 Kg/m3	1:16 to 1:20 by weight sorbent to oil	Sinks when wet; displays better buoyancy when oil soaked. Structurally weakens upon prolonged contact with water.
Peat Moss, organic fibre	Bulk Density 82 to 171 Kg/m3 dependant on particle size & moisture content	1:8 to 1:12 by weight sorbent to oil	Sinks when wet.
Slikwik, (organic) ground corn cobs	Bulk Density 141 Kg/m3	1:5 by weight sorbent to oil	Fresh crude or distillate fuels in bay, harbour, shore or estuary
Fiberperl, (mixed organic/inorganic) expanded perlite & cellulosic fibres	Bulk Density 72 Kg/m3	13.3% of sorbent sank during 1st step of oil/water pref. test. 1:5 to 1:7 by weight sorbent:oil	Dust is an irritant.

Type of Sorbent Tested	Physical Properties	Performance	Comments
Solid Solvent (mixed organic/inorganic) experimental polymer coating	Bulk Density N/A	Type of spills - light & medium oils, diesel fuel	-----
Imbiber Beads (true absorbing/imbibing polymer)	Bulk Density 626 Kg/m3	Oil pickup ratio varies with fluid type; typical are gasoline at 50:1 & No.2 diesel oil up to 27:1 by weight	Available forms include beads, packets, blankets, valves, hazardous shipping packages, immobilization systems for hazardous and low level nuclear contaminated oily wastes. Recommended for use with heavy oils.
Graboil - treated polyurethane foam (synthetic polymer)	Bulk Density 19 Kg/m3	Oil pickup ratio 1:23-1:33 Sorbent:oil	Type of spill - light to heavy oils. Recommended dosage; 1:35 sorbent:oil Must be forced into oil initially. For heavy oils, action is one of adsorption for light oil, absorption is by capillary action.
Hazorb - (synthetic)	Bulk Density N/A	Oil pickup ratio approx. 1:3 for solvents and light oils; 1:8 to 1:10 for heavy oils.	Exhibits very high water pickup with solvents and light oils but not with heavy oils.
Quick Wick - treated polypropylene	Bulk Density approx 45 Kg/m3	Oil pickup ratio 0.6 kg/min/cm2 (manufacturer); 1:6 to 1:8 sorbent:oil (this study)	Type of spill - petroleum products

Type of Sorbent Tested	Physical Properties	Performance	Comments
Spill Control Company FPD Pad - polyurethane chips bonded together	Bulk Density N/A	Oil pickup ratio 1:40 to 1:60 sorbent:oil by weight (manufacturer); 1:5 to 1:15 sorbent:oil (this study).	Will not sink even when fully saturated, applicable for all oils
Spill Control Company PEP Pad - polyether base	Bulk Density N/A	Oil pickup ratio: 1:40 to 1:60 sorbent:oil by weight (manufacturer); 1:10 to 1:30 sorbent:oil (this study)	Designed for low viscosity oils: very reuseable.
Spill Control Company SPD Pad - polyester base	Bulk Density N/A	Oil pickup ratio: 1:40 to 1:60 sorbent:oil by weight (manufacturer); 1:5 to 1:10 sorbent:oil (this study)	Designed for heavy viscosity oil recovery.
SPC Oil Sorbent Pads - polyethylene fabric	Bulk Density 40 Kg/m3	Oil pickup ratio depends upon viscosity of oil; the more viscous, the poorer the results. Up to 1:13 sorbent:oil with cyclohexane.	Direct relationship to viscosity of liquid being picked up; gasoline and diesel are immediately picked up.
3M Type 156 Pads - polyethylene fabric	Bulk Density 40 Kg/m3	Oil pickup ratio ranges from 1:14 to 1:22 sorbent:oil by weight	Water resistant. Used to remove rainbow sheens of fuel oil and other oils up to the viscosity of motor oils. Indefinite shelf life if stored away from direct sunlight or other

Type of Sorbent Tested	Physical Properties	Performance	Comments
Modified Pine Bark	Bulk Density 0.25 Kg/L	Oil pickup ratio 1:1 to 1:3 sorbent:oil; minimal water pickup	Recommended dosage; 1:3 sorbent:oil by weight
Verdyol - specially treated vegetable fibres	Bulk Density 300 Kg/m3	Oil pickup ratio 1:42 sorbent:oil (manufacturer); 1:19 to 1:13 sorbent:oil (this study).	Biodegradable; must be kept in dry location. Type of spill; ocean and inland water spills of oils ranging in viscosity from No.2 Fuel Oil to Bunker C.
AB & B Pads - polypropylene fabric	Bulk Density N/A	Oil pickup ratio 1:3 to 1:6 sorbent:oil	Manufacturer recommends use on lighter oils.
AB & B Swabs - polypropylene yarns	Bulk Density N/A	Oil pickup ratio 1:2 to 1:3 sorbent:oil for solvents and light oils; up to 1:20 for heavy oils.	Manufacturer recommends use on heavier oils.
Alsorb - polypropylene fabric	Bulk Density N/A	Oil pickup ratio 1:9 to 1:16 sorbent:oil by weight	Recommended for use around equipment and for heavy oils.
Conwed D Sorbent Pads - closed cell polyethylene foam	Bulk Density 38 Kg/m3	Will hold up to 23 times it own weight in No.5 Fuel Oil; similar capacity observed in this study for light oils and solvents.	Type of spill - petroleum products and certain non-miscible chemicals. Recommended dosage; 1:15 to 1:20 sorbent:oil by weight.

Type of Sorbent Tested	Physical Properties	Performance	Comments
Conwed Petro Mesh - rectangular plastic netting made into "pom-poms"	Bulk Density N/A	Oil pickup ratio 1:9 sorbent:oil for No.6 Fuel Oil (manufacturer); this study <1:1 sorbent:oil for solvents and light oils, up to 1:20 for heavy oils.	Recommended for heavy oils. UV light will weaken fibre.
Oil Snake - polyolefin yarn	Bulk Density 142.6 Kg/m3	Oil pickup ratio 1:3 to 1:64 sorbent:oil	Recommended for use with heavy oils.

APPENDIX B

ASTM METHOD D 1117-80

STANDARD METHODS OF TESTING NONWOVEN FABRICS

The following sections are abstracted, with permission, from the Annual Book of ASTM Standards, copyright American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA, 19103.

5. ABSORBENCY TIME AND ABSORPTIVE CAPACITY

5.1 SCOPE- These methods cover three procedures for evaluating the ability of a nonwoven fabric to hold or retain moisture, as follows:

5.1.1. Absorbency Time Test,

5.1.2. Absorptive Capacity Test (for small test specimens), and

5.1.3. Absorptive Capacity Test (for larger test specimens).

5.1.4. These procedures are useful in appraising the absorbency of napkins, towels, diapers, and similar materials

5.2 ABSORBENCY TIME TEST:

5.2.1. Apparatus:

5.2.1.1. Cylindrical Wire Basket, open at one end, 8 cm high, 5 cm in diameter, weighing 3 to 8 g and constructed of No. 20 to 26 gage B and S copper wire in such a manner that the wires form a mesh approximately 2 cm square.

5.2.1.2. Container of Water

5.2.2.2. Test Specimens- Cut five test specimens of the nonwoven fabric in the machine direction, each 76 mm wide and of such length that the weight of each strip is 5+ 0.1 g. Take these strips at approximately equally spaced intervals across the sample sheet.

5.2.3. Procedure

5.2.3.1. Make the test at room temperature. Roll each test specimen into a loose roll of about the same diameter as that of the cylindrical basket. Place the specimen, loosely packed, in the basket, with its 76 mm edge parallel to the side of the basket so that the specimen fills the basket.

5.2.3.2. Drop the basket on its side from a height of 25 mm into a suitable container of water at room temperature, and measure with a stop watch the time in seconds required for complete wetting of the specimen. Detect the end point by noting the progress of the water through the specimen.

5.2.4. Calculation and Report-Report the average of five determinations as the value of the absorbency test.

5.3. ABSORPTIVE CAPACITY TEST (for small test specimens):

5.3.1. Apparatus

5.3.1.1. Watch glass, tared, 127 mm in diameter.

5.3.2. Test Specimens - Use the same test specimens in this method that were used in the absorbency time test.

5.3.3. Procedure-After the absorbency time has been determined, allow the basket and specimen to remain submerged in the water for 10 s. Then, remove by grasping the open end of the basket. Allow it to drain for 10 s with the open end up and then immediately weigh the basket and its contents to the nearest 0.1 g in the 127 mm watchglass.

5.3.4. Calculation and Report-Calculate the weight of the water held by the specimen by subtracting the sum of the weights of the water glass, the basket and the dry specimen from the total. Report the absorptive capacity as the ratio of the water held in the specimen to the weight of the dry sample, or "times own weight". Report the average of five test specimens as the value for absorptive capacity in this test.

5.4. ABSORPTIVE CAPACTIY TEST (for Larger Test Specimens):

5.4.1. Apparatus:

5.4.1.1. Galvanized Screen, tared, measuring 230 mm by 230 mm and construced of No. 17 gage B and S wire about 2 mesh to 1 in (25.4 mm).

5.4.1.2. Pan, 76 mm deep by 254 mm wide by 254 mm long.

5.4.1.3. Pan, tared, shallow, lighweight, and large enough to hold the galvanized screen.

5.4.2. Test Specimens-In those cases where it is desired to use a larger and possibly more representative test specimen, take a specimen measuring 200 mm by 200 mm and consisting of six plies cut at approximately equally spaced intervals across the sample sheet, on a line 45 deg to the edge of the sheet. If the specimen is excessively bulky, or weighs more than 77.5 g/m2 (1000 grains/yd2) or both, three plies may be used instead of six. In either case, take three specimens for the test.

5.4.3. Procedure:

5.4.3.1. Weigh the test specimen to the nearest 0.1 g at room temperature and place it on the 230 mm by 230 mm galvanized wire screen. Place the specimen and screen in the 76 mm deep pan containing water at room temperature about 64 mm deep. The specimen may float temporarily until it is thoroughly wetted.

5.4.3.2. After the specimen is completely wetted, allow it to stay in the water for 1 minute then raise the screen with the specimen on it above the water, hold in a horizontal position, and allow to drain for 10 minutes by resting the screen on sticks of wood or pieces of metal placed across the top of the pan near the ends of the screen.

5.4.3.3. After draining, place the screen and the test specimen in a tared pan and weigh the pan and its contents as carefully as possible to the nearest 0.1 g.

5.4.3.4. Calculation and Report - Calculate the amount of water held by the specimen by subtracting the sum of the weights of the weighing pan, screen, and dry specimen from the total weight. Report the absorptive capacity as the ratio of the water held by the specimen to the weight of the dry specimen or "times own weight". Report the average of the three values found as the absorptive capacity.

APPENDIX C

PHOTOMICROGRAPHS AND PHOTOGRAPHS

Photomicrographs

Figure No.	Sample Material	Magnification
C-1	Ultra Absorbent Diaper	380X
C-2	White Foam (low density polyurethane foam)	95X
C-3	Yellow Foam (high density polyurethane foam)	95X
C-4	Hydrathane (high density reticulated polyurethane foam incorporating super absorbent polymers)	95X
C-5	Chemsorb (granular amorphous silicate)	95X
C-6	SorbX (cellulose/polypropylene blend)	95X
C-7	Rayon Sheet	95X

Photographs

C-8	Absorbency Testing Apparatus (Fibrous Absorbents and Foams)	1X
C-9	Absorbency Testing Apparatus (Granular Absorbents)	1X
C-10	Analytical Balance and High/Low Temperature Test	1X
C-11	Compression, Wicking and Controlled Temperature/ Humidity Chamber	1X
C-12	Vibration Test Rack	1X

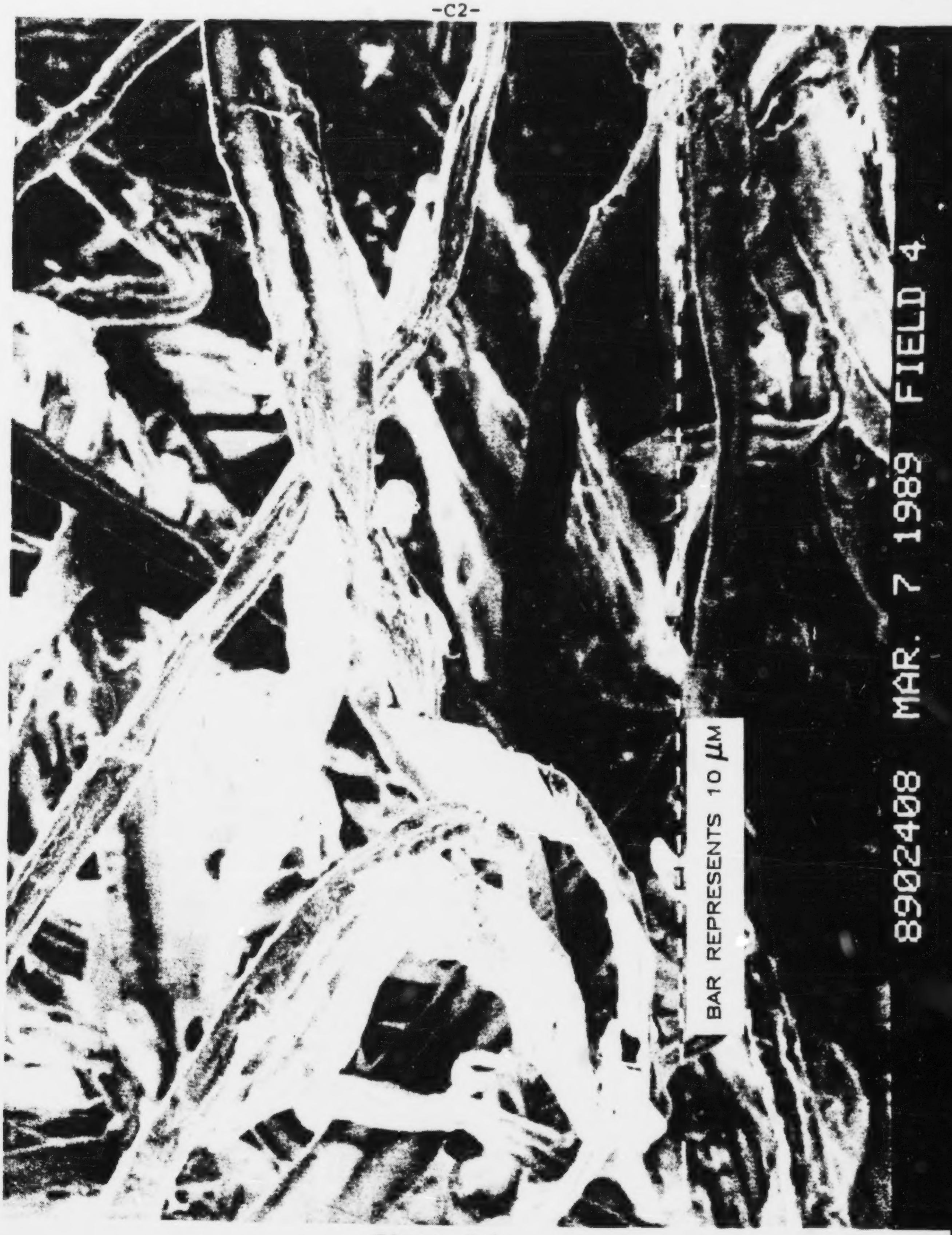

Figure C-1
Ultra Absorbent Diaper Material
380X Magnification

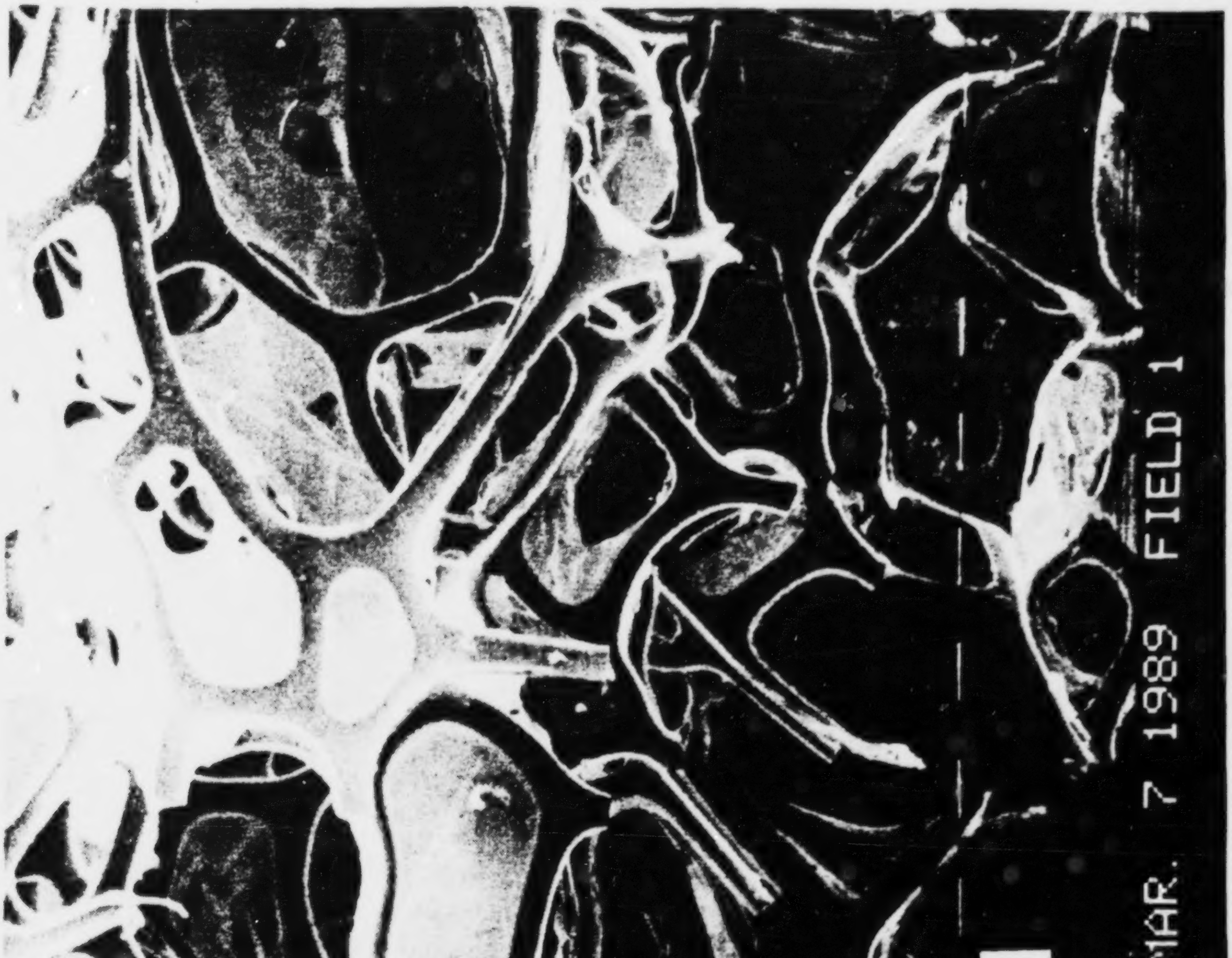

Figure C-2

White Foam (Low Density Polyurethane Foam)

95X Magnification

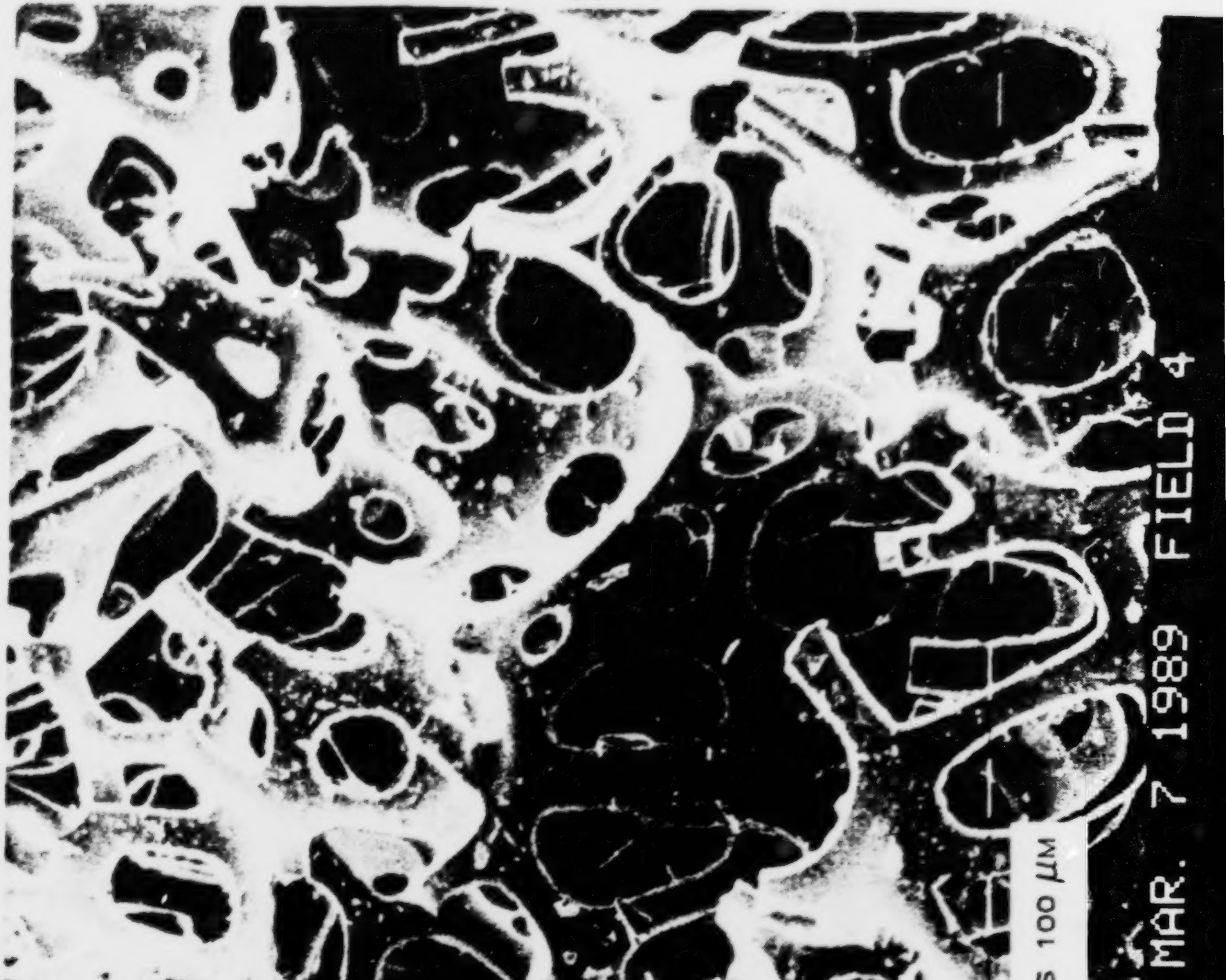

Figure C-3

Yellow Foam (High Density Polyurethane Foam)

95X Magnification

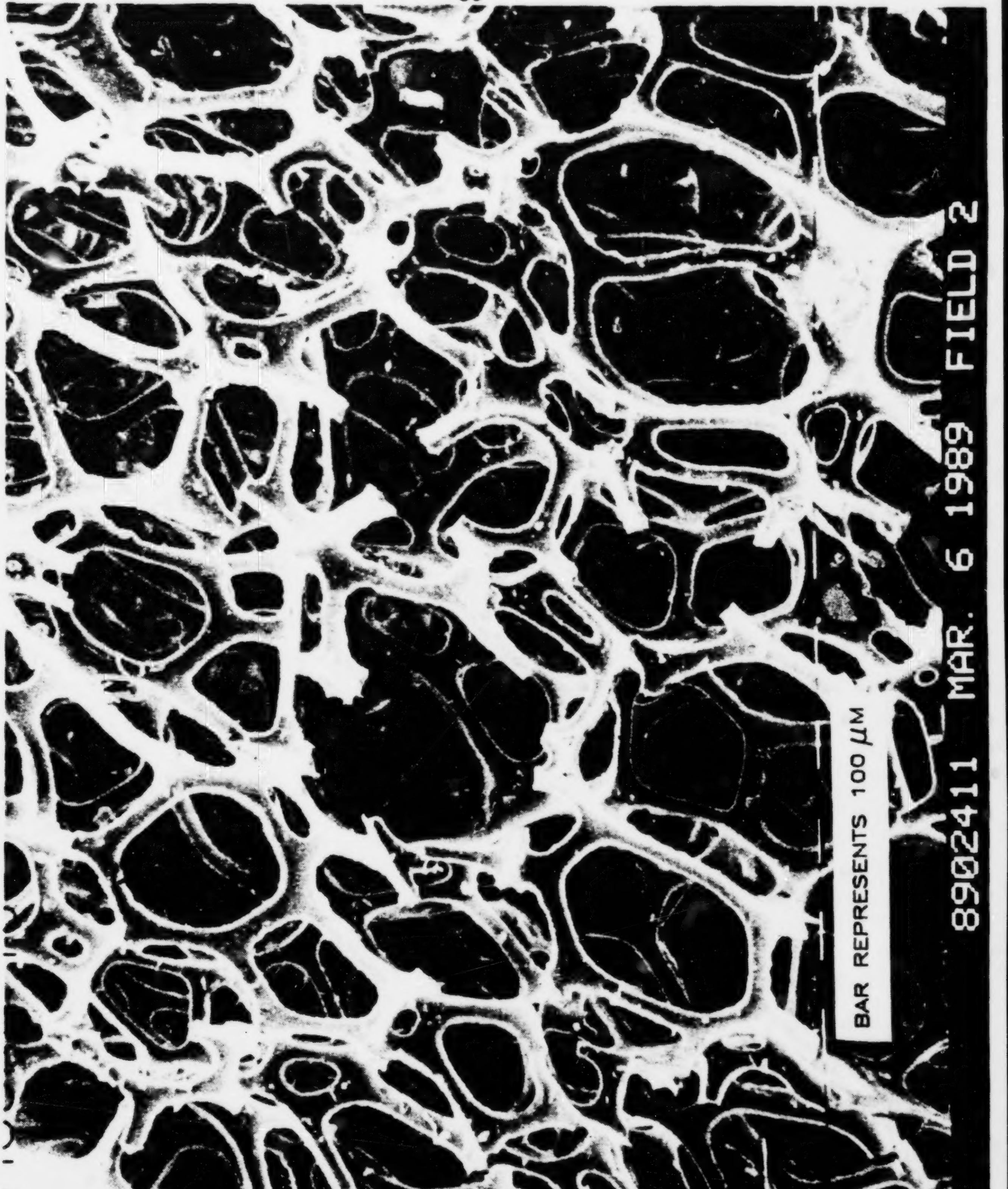

Figure C-4

Hydrathane^{tm}(High Density Foam with SAP)

95X Magnification

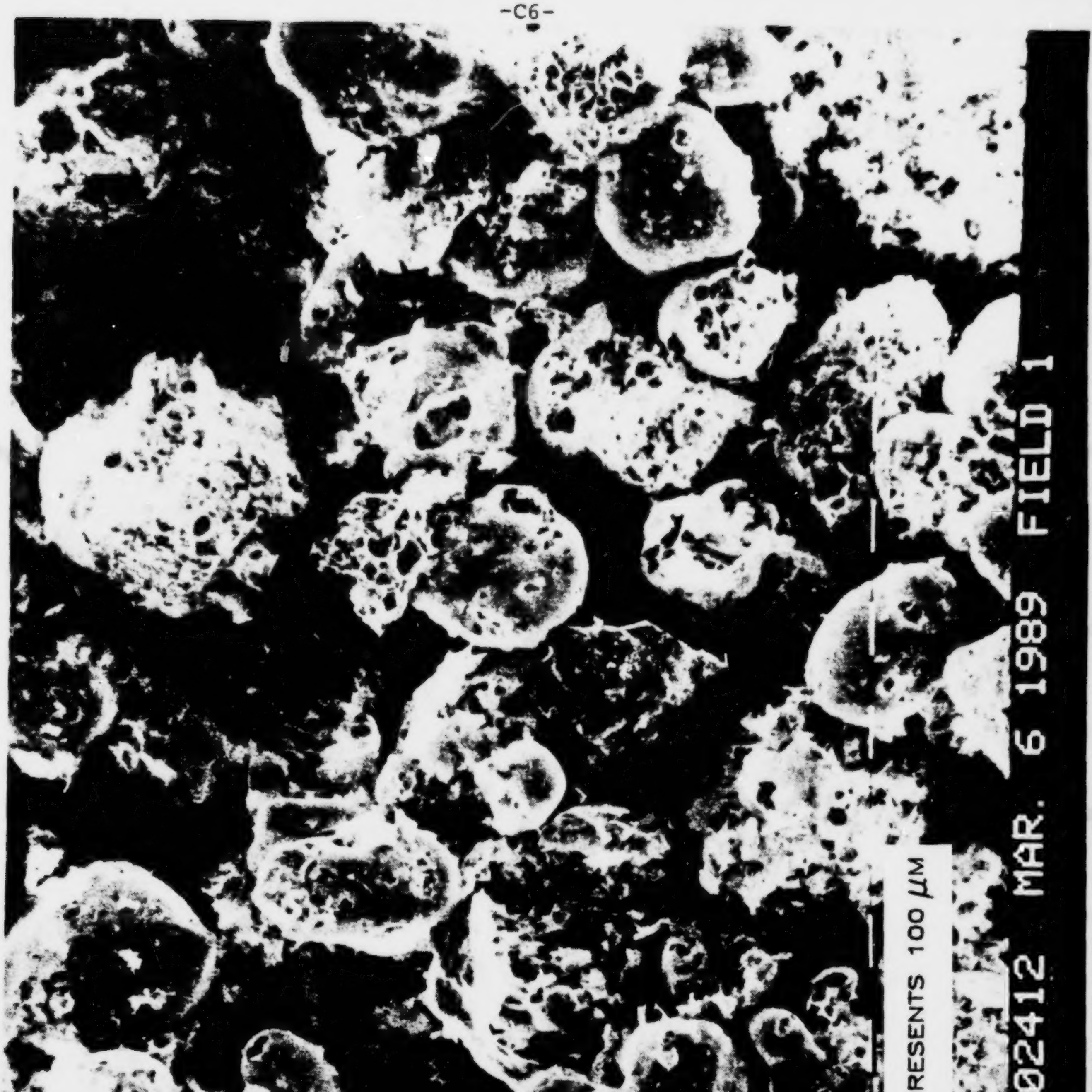

Figure C-5

Chemsorb^{tm} (Granular Amorphous Silicate)

95X Magnification

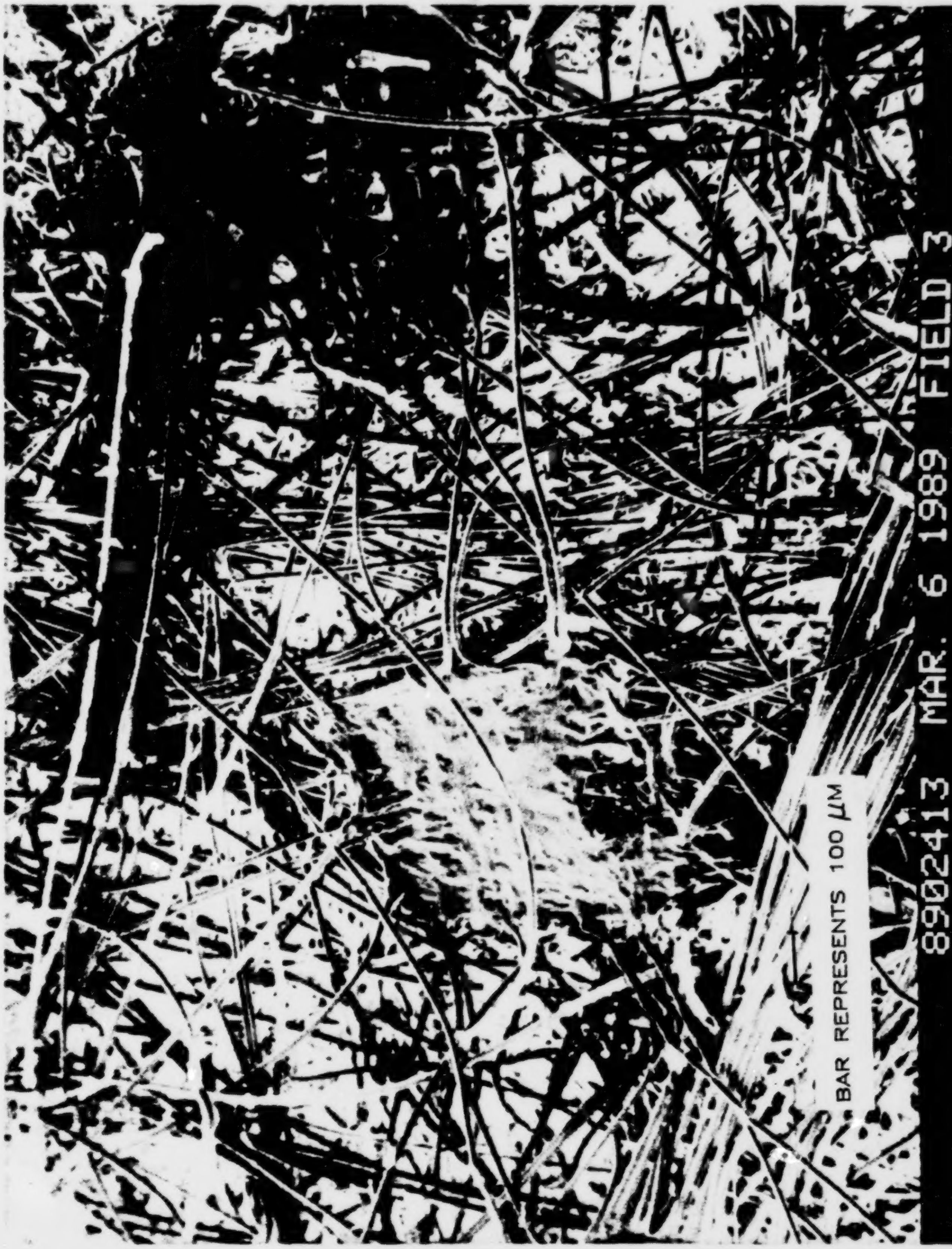

Figure C-6

SorbX^{tm} (Cellulose/Polypropylene Blend)

95X Magnification

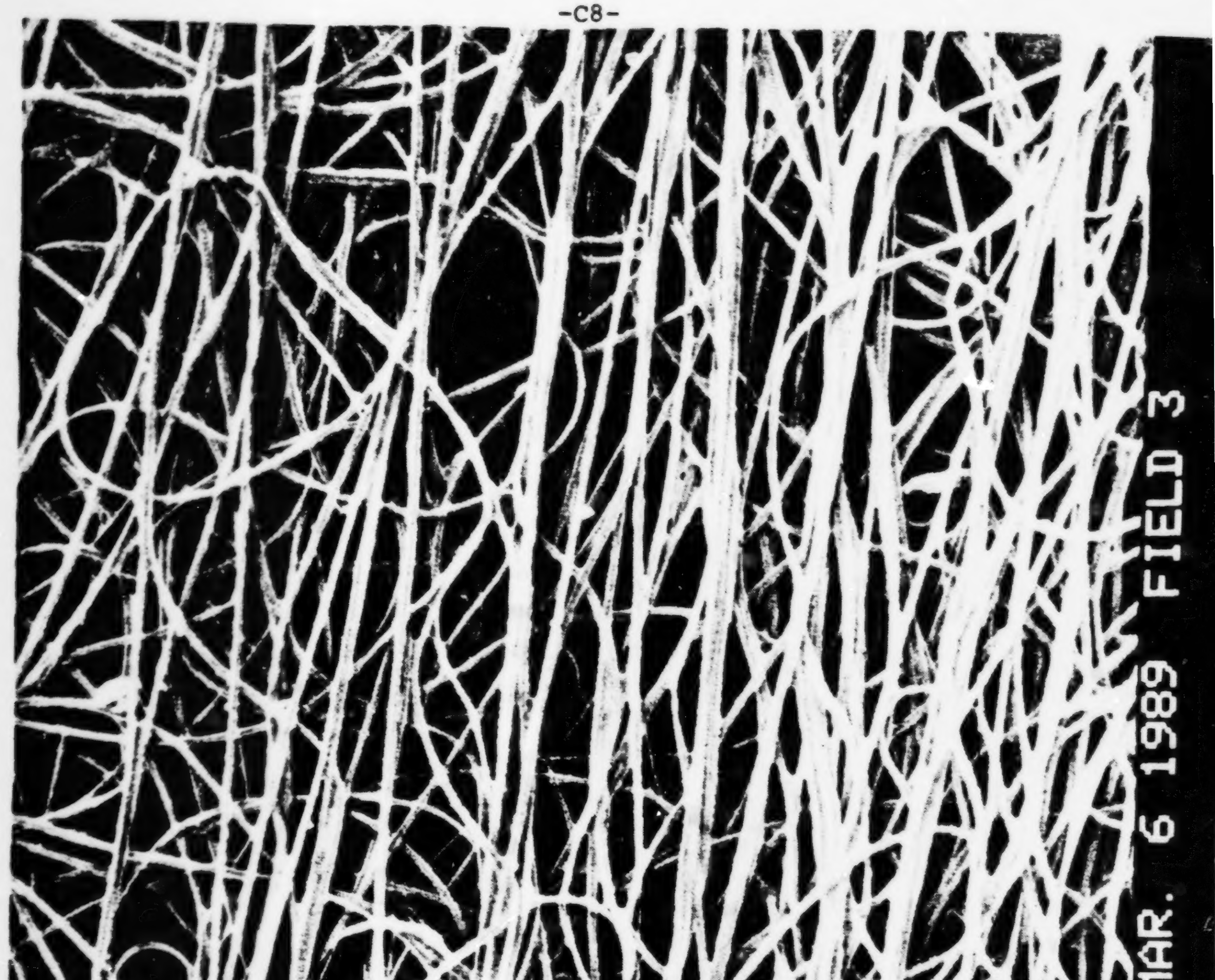

Figure C-7

Rayon Sheet

95X Magnification

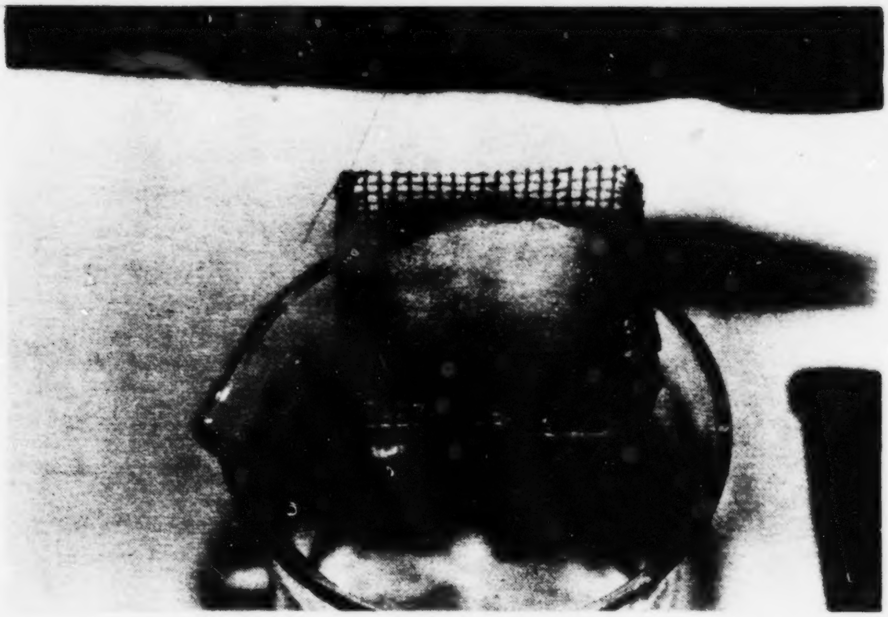

Figure C-8(a)
Wire Basket for Fibrous Absorbents

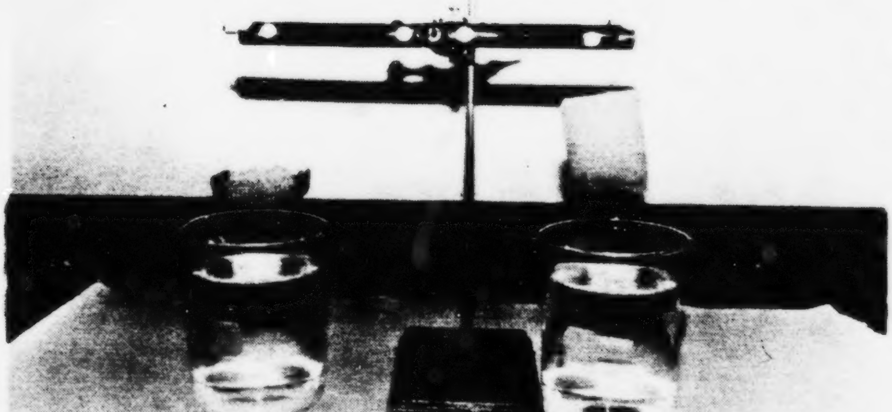

Figure C-8(b)
Ultra Diaper (Left) and Foam Block (Right) Under Test
Absorbency Testing Apparatus

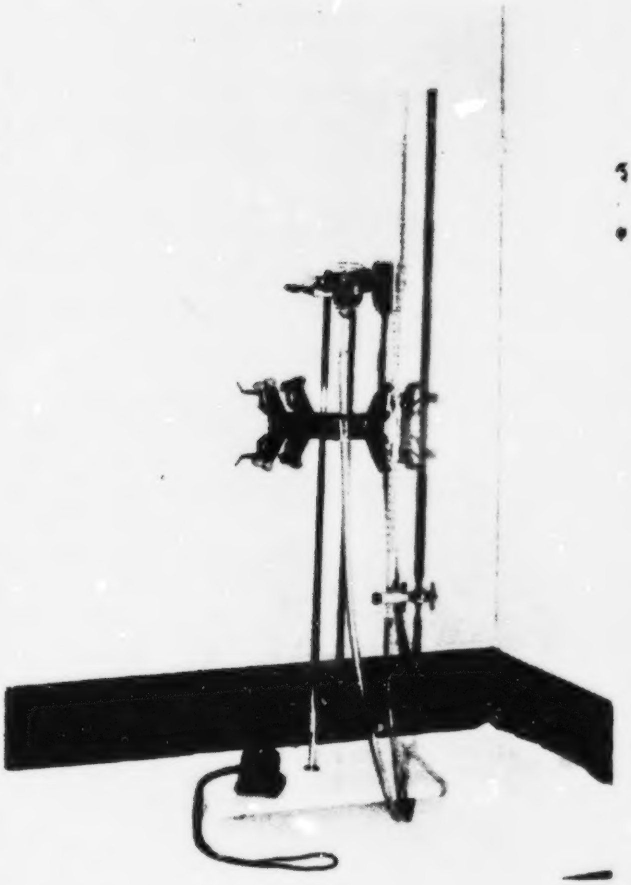

Figure C-9(a)
Granular Absorbent
Test Apparatus

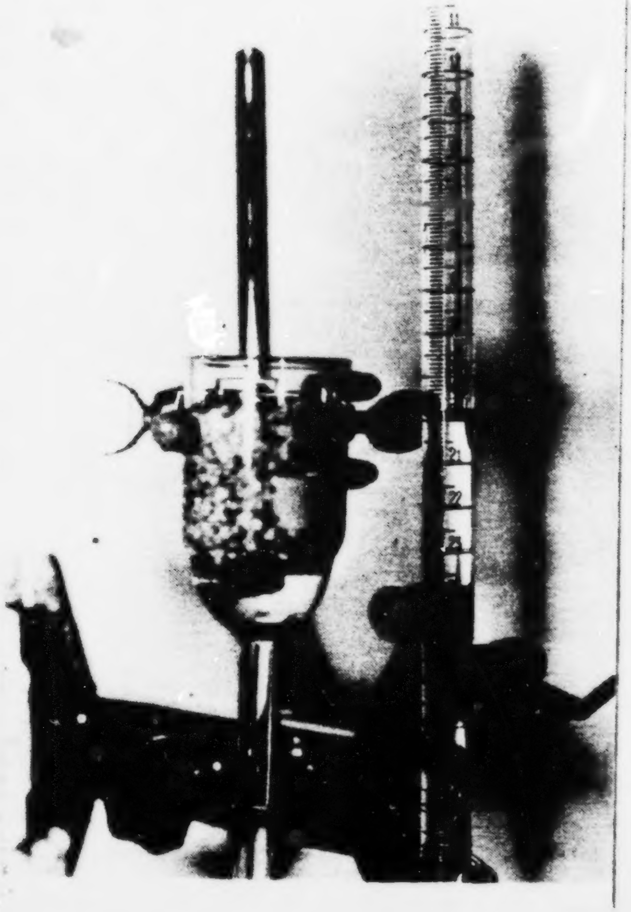

Figure C-9(b)
Vermiculite Under Test

Absorbency Testing Apparatus

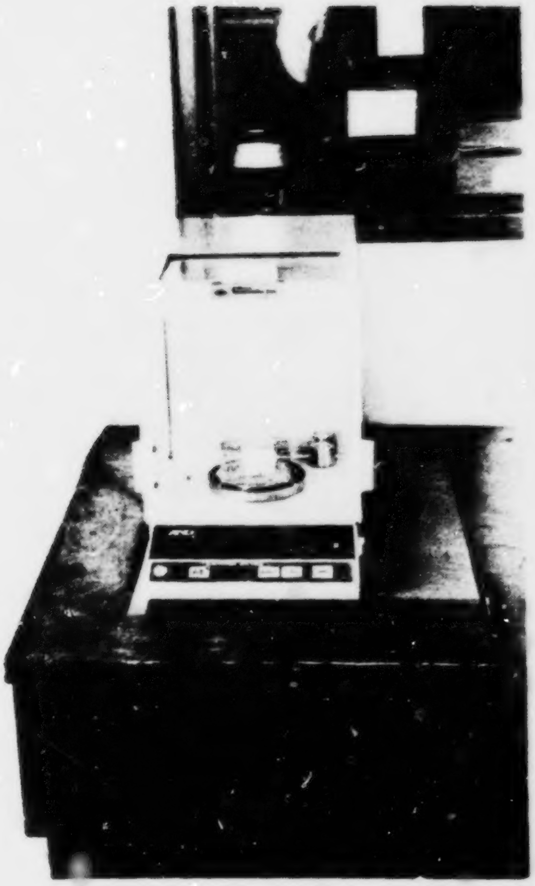

Figure C-10(a)
Analytical Balance

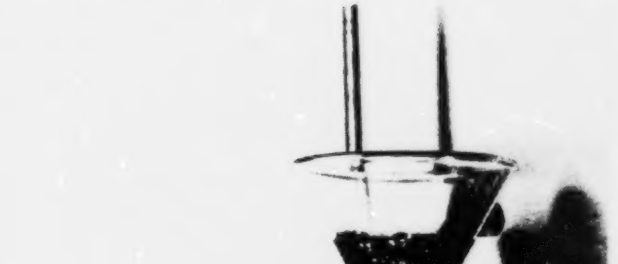

Figure C-10(b)
Granular Absorbent
Test Apparatus
(Used only for temperature
effects testing inside oven
or cold chest)

Absorbency Testing Apparatus

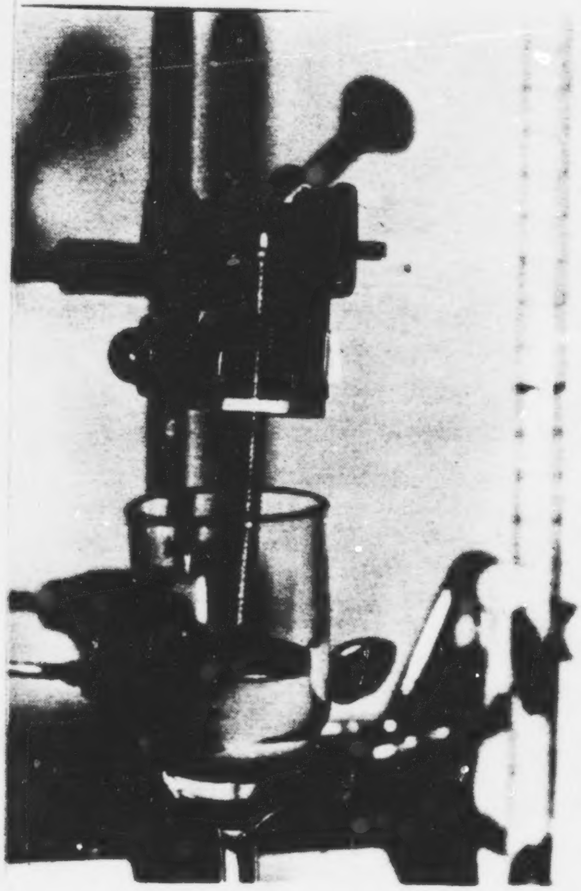

Figure C-11(a)
Compression Testing Apparatus

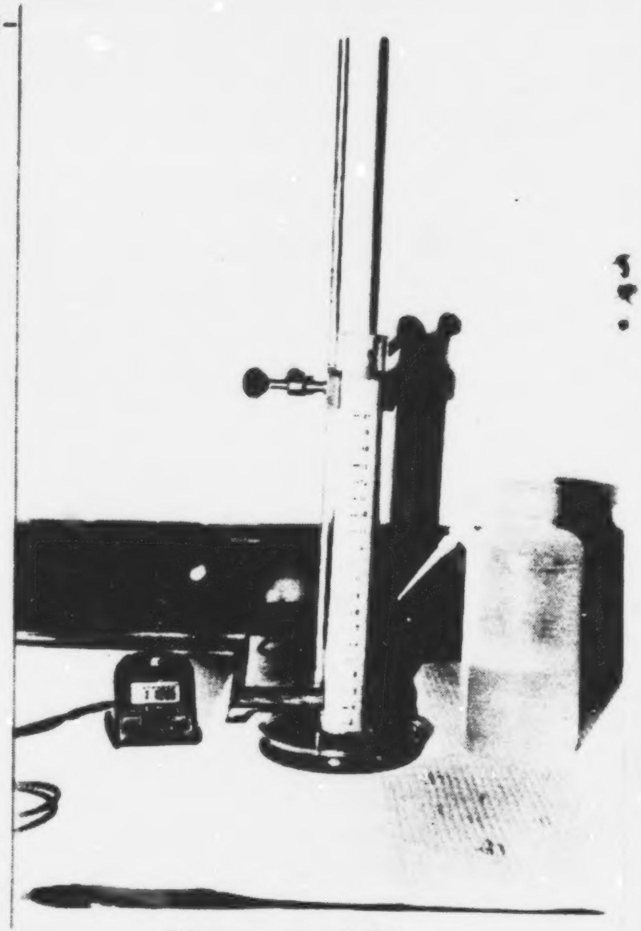

Figure C-11(b)
Wicking Test Apparatus

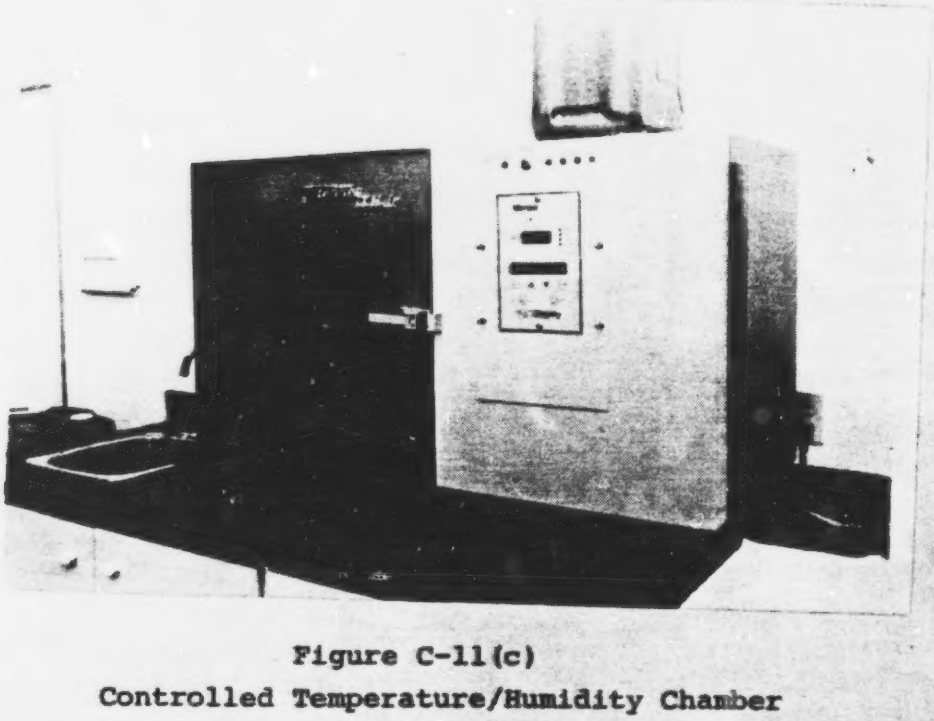

Figure C-11(c)
Controlled Temperature/Humidity Chamber

Figure C-12
Test Rack for Vibration Road Test